# Final Report

# Safe School Bus Demonstration Program Support

**Interagency Agreement 500-95-004**

**Prepared for:**
**California Energy Commission**
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## Legal Notice



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## Glossary

ANOVA................................ Analysis of Variance

ANT .................................. Antelope Valley Unified School District (Lancaster, California)

CBD .................................. Central Business District test cycle

CEC .................................. California Energy Commission

CE-CERT ............................. College of Engineering-Center for Environmental Research and Technology, University of California, Riverside

CLO .................................. Clovis Unified School District (Clovis, California)

CNG .................................. Compressed Natural Gas

CO .................................. Carbon monoxide

DAS .................................. Data Acquisition System

DDEC .................................. Detroit Diesel Electronic Control

HC .................................. Hydrocarbons

ITEM .................................. Integrated Transportation/Emissions Model

KNY .................................. Kings Canyon Unified School District (Reedley, California)

M100 .................................. Methanol (100 percent methanol)

M85 .................................. Methanol (85 percent methanol, 15 percent gasoline)

Meth .................................. Methanol

NOx .................................. Oxides of nitrogen

QA/QC.................................. Quality Assurance/Quality Control

QCP .................................. Quality Control Plan

RPM ………………………Revolutions per minute

SBIS...................................... School Bus Information System

## Abstract

A subset of the alternative-fuel school buses provided by the California Energy Commission to districts in the state was evaluated for fuel consumption, maintenance cost, and other operational characteristics. CE-CERT developed data collection and validation methods to compare control (pre-1977) diesel buses, advanced diesel buses, methanol buses, and compressed natural gas-fueled buses. Results indicate that bus routes, drivers, and fuel quality have an effect on overall cost-effectiveness. Overall, however, newer generations of diesel and compressed natural gas-fueled buses demonstrated operating costs per mile lower than those of previous generations, and comparable with each other. Significant improvements in operational cost per mile were found in both diesel and CNG buses. It is recommended that further research be carried out on emissions from these vehicles, and that a uniform testing cycle be developed for more precise comparison of school buses free of outside influences such as route length and type, urban/rural setting, climate, and elevation. Further study of fuel quality as an influence on operating performance and cost also is recommended, especially for compressed natural gas vehicles.

# 1. Introduction

The California Energy Commission (Commission) is nearing completion of the Safe School Bus Clean Fuel Efficiency Demonstration Program. Through this project (now entering its fourth and final phase), the Commission is replacing school buses manufactured before April,1977, the year federal minimum safety standards were made more stringent, with new buses designed to be safer, cleaner, and more cost-effective to operate. Buses operating on "clean" diesel fuel, methanol, and compressed natural gas.

The Commission has worked with school districts, the National Renewable Energy Laboratory (NREL), the University of California, Riverside, College of Engineering-Center for Environmental Research and Technology (CE-CERT), and Acurex Environmental Corporation to collect data on vehicle fuel consumption, reliability, maintenance, and mileage accumulation. The Commission established the School Bus Information System (SBIS) to collect, store, and analyze data from all of the school buses in the program. Data are collected manually by school district personnel and, in some cases, automatically by 113 data loggers. The school districts have been provided with software and training to enable them to record and enter operational and maintenance data for transfer to the Commission.

A critical need was identified to evaluate these data and reach conclusions about vehicle performance. This was a challenging task because of the wide variety of engine and fuel types placed into service under this program and because school districts in California have a wide variety of needs — some operate in low-speed urban settings, some in suburbs, and some in rural areas with large amounts of highway driving.

Under Interagency Agreement 500-95-004, CE-CERT has carried out four tasks:

1. Development of a Project Work Plan, which included identifying school districts to participate in data collection and development of methodology.

2. Preparation for data collection, which included the procurement, calibration, and installation of data acquisition equipment; training of district personnel; and establishment of procedures to capture the data.

3. Data collection, scheduled to take place for one year.

4. Data reduction, analysis, and reporting.

The methodologies for these tasks are discussed in Section 2. Results of this project have included development of improved methods for logging vehicle operational data; for comparing fuel consumption of vehicles operating on different gaseous and liquid fuels; and for analyzing vehicle performance on a wide variety of routes and terrain. Results are discussed in Section 3, and recommendations based on these results are presented in Section 4.

# 2. Technical Approach

## 2.1 Background

The Safe School Bus Clean Fuel Efficiency Demonstration Program (School Bus Program) was created by California Assembly Bill 35 (Chapter 1426, Statutes of 1988). It is a four-phase program administered by the Commission designed to facilitate the commercial availability of alternatively-fueled school buses to school districts that have been specially selected based on their location, fleet age, and ability to maintain and operate the buses. In return for the buses, the school districts are required to provide the Commission with operational and maintenance data for the new demonstration buses and selected pre-1977 school buses over a five-year period.

In Phase 1, 163 buses were placed in 14 school districts (103 advanced diesel, 50 M85 (85% methanol, 15% gasoline and 10 CNG). In Phase 2, 400 buses were placed in 47 school districts (200 advanced diesel, 100 M85 (100% methanol) and 100 CNG). Forty-two M85 buses at three school districts were subsequently converted to operate on M100 on a limited test basis. In Phase 3, 218 additional buses were placed in 47 school districts (107 advanced diesel, 107 CNG, and 4 electric). The location and type of buses delivered during Phases 1-3 are summarized in Table 2-1.

The objective of the school bus program is to conduct a demonstration of new school buses that meet or exceed all applicable Federal Motor Vehicle Safety Standards, and to demonstrate the economic and technical feasibility of using alternative fuels in school buses. Using data collected from the demonstration buses and pre-1977 control buses, the Commission will determine whether the use of alternative fuels results in lower levels of adverse exhaust emissions and greater operating efficiency than similar conventional fuel buses. In addition, the Commission plans to compile life cycle costs for alternative fuel buses as compared to conventional fuel buses.

As described in the Data Collection Plan[1], the Commission and its subcontractors have developed the School Bus Information System (SBIS) to collect, store, and analyze data from all of the school buses provided to school districts as part of the School Bus Program. Data are collected manually by school district personnel and, in some case, automatically by 113 data loggers. The school districts have been provided with software and training to enable them to record and enter operational and maintenance data for transfer to the Commission.

The data set generated from the original data collection was larger than necessary for valid statistical results. In addition, the labor required to implement the necessary quality control measures on this large data set was beyond current resources. Therefore, the Commission contracted with CE-CERT at UC Riverside to perform a focused study on a representative subset of the demonstration and pre-1977 buses. The goal of the focused study is to provide factual data and comparisons of the operational characteristics and cost of the various bus/engine types in the

School Bus Program, using a statistically valid, representative subset of buses and school districts.

## Table 2-1
## Demonstration Host Sites and Buses

| Participating School Disticts | Diesel | | | Methanol | | CNG | | | Elctc | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Phase*** | **1** | **2** | **3** | **1** | **2** | **1** | **2** | **3** | **3** | |
| ABC Unified SD(Cerritos) | | 4 | 2 | | | | | | | 6 |
| Alhambra SD | | | 5 | | | | | | | 5 |
| Anderson Union H.S. | | | 2 | | | | 6 | 2 | | 10 |
| ***Antelope Valley STA (Lancaster)*** | | **8** | | | **16** | | **16** | **12** | **1** | **53** |
| Berkeley Unified SD | | 5 | 5 | | | | | | | 10 |
| Bonita Unified SD (San Dimas) | | | 3 | | | | | | | 3 |
| Central Unified SD (W. Fresno) | | 5 | 4 | | | | | | | 9 |
| Centralia Unified SD (Orange) | | | 2 | | | | | | | 2 |
| Chaffey Jt. Union (Ontario) | | 3 | 3 | | | | | | | 6 |
| Chico Unified SD | 3 | 5 | 3 | | | | | | | 11 |
| Chula Vista Elementary SD | | 2 | | | | | 7 | 4 | | 13 |
| ***Clovis Unified SD*** | **18** | | **5** | **13** | **5** | | | **6** | **1** | **48** |
| Coachella Valley Unified SD (Thermal) | | 5 | | | | | | | | 5 |
| Coalinga-Huron Unified SD | | 3 | | | | | | | | 3 |
| Colton Joint Unified SD | | | 3 | | | | | | | 3 |
| Covina Valley Unified SD | | 3 | | | | | | | | 3 |
| Del Norte County Unified SD (Cresent City) | | 7 | | | | | | | | 7 |
| Fremont Unified SD | | | 6 | | | | | | | 6 |
| Fresno Unified SD* | 14 | | | 10 | | | | | | 24 |
| Fullerton Union H.S. | | | 4 | | 8 | | | | | 12 |
| Garden Grove Unified SD* | 3 | | | | | | | | | 3 |
| Gateway Unified SD (Redding) | | | 4 | | | | | | | 4 |
| Hayward Unified SD | | | | | | 3 | 4 | | | 7 |
| Huntington Beach City SD | | | 2 | | | | | | | 2 |
| Kern County Consortium (Bakersfield) | 8 | 16 | | | | | | | | 24 |
| Kern H.S. (Bakersfield) | | 5 | | | | | 10 | 12 | | 27 |
| ***Kings Canyon Unified SD(Reedley)*** | | **3** | **5** | | **3** | | | **5** | **1** | **17** |
| Lassen Union H.S. (Susanville) | | 6 | 4 | | | | | | | 10 |
| Lemoore H.S. | | | 1 | | | | | 1 | | 2 |
| Lompoc Unified SD | | | 1 | | | | 10 | 5 | | 16 |
| Los Angeles Unified SD* | 15 | | | 12 | | 4 | | | | 31 |
| Lucia Mar Unified SD (Arroyo Grande) | | | 4 | | | | | | | 4 |
| Mid-Placer Public Schools (Auburn) | | 10 | 2 | | | | | | | 12 |
| Mountain Areas Consortium (Yosemite) | | 5 | | | | | | | | 5 |
| Napa Vallley Unified SD | 6 | 3 | | | | | | | | 9 |
| New Haven Unified SD (Union City)* | 2 | | | | | | | | | 2 |
| Newport-Mesa Unified SD (Costa Mesa) | | 3 | | | | | | | | 3 |
| Novato Unified SD | | | 2 | | | | | | | 2 |

## Table 2-1 (cont.)

| Participating School Disticts | Diesel | | | Methanol | | CNG | | | Elctc | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Phase*** | **1** | **2** | **3** | **1** | **2** | **1** | **2** | **3** | **3** | |
| Oceanside Unified SD | | | 1 | | | | | 6 | | 7 |
| Orange Unified SD | | 3 | | | | | | | | 3 |
| Oxnard Union H.S. | | | | | 5 | | | | | 5 |
| Paradise  Unified SD | | | 4 | | | | | | | 4 |
| Plumas Unified SD (Quincy) | | 5 | 2 | | | | | | | 7 |
| Porterville Public Schools | | 3 | | | | | | | | 3 |
| Poway Unified SD | | | | | | | 10 | 6 | | 16 |
| Pupil Transportation Cooperative (Whittier) | | 4 | | | 7 | | | | | 11 |
| Red Bluff Union High Bus Consortium | | 7 | | | | | | | | 7 |
| Redlands Unified SD | | 10 | 2 | | 5 | | | | | 17 |
| Rialto Unified SD | 8 | 5 | | 7 | | | | | | 20 |
| Rincon Valley Unified SD (Santa Rosa) | | | 1 | | | | | 1 | | 2 |
| Riverside Co. Alternative Fuels Consortium | | 7 | | | 11 | | | | | 18 |
| Rowland Unified SD | | 3 | 3 | | 5 | | | | | 11 |
| Sacramento Consortium | | 4 | | | 14 | | 10 | 5 | | 33 |
| Sanger Unified SD | 3 | 2 | | | | | 5 | 5 | | 15 |
| San Dieguito Unoin H.S. (Encinitas) | | | | | | | | 5 | | 5 |
| San Luis Obispo County Consortim | | 5 | | | 5 | | 9 | | | 19 |
| San Mateo Union H.S. | | | 2 | | | | | | | 2 |
| Simi Valley Unified SD | | | 2 | | | | | | | 2 |
| South Bay Union SD (Imperial Beach) | | 3 | | | | | 3 | | | 6 |
| Southwest Transportation Agency (Riverdale) | | | | | | | 10 | 3 | | 13 |
| Sweetwater Union H.S. | | | 2 | | | | | 4 | | 6 |
| Sylvan Unified SD (Modesto) | | | 4 | | | | | | | 4 |
| Tahoe/Truckee Unified SD | | 5 | 6 | | 5 | | | | | 16 |
| Tehachapi Unified SD | | 5 | | | 3 | | | | | 8 |
| Tular Joint Union H.S. | | | 2 | | | | | | | 2 |
| Tulare County Org. for Vocational Education | | | 1 | | | | | 1 | 1 | 3 |
| Upland Unified SD | | 3 | | | | | | | | 3 |
| Vallejo City Unified SD | | 3 | | | | | | | | 3 |
| Ventura Unified SD | 8 | | | 4 | | | | 5 | | 17 |
| Victor Valley Consortium | 15 | 5 | | 4 | 8 | | | 5 | | 37 |
| Visalia Unified SD | | | 1 | | | | | 4 | | 5 |
| Vista Unified SD* | | | | | | 3 | | | | 3 |
| West County Trans.  Agency (Sebastopol) | | 12 | 2 | | | | | 7 | 1 | 22 |
| Western Slope Consortium (Pollock Pines) | | 5 | | | | | | | | 5 |
| ***Phase Total*** | **104** | **202** | **110** | **51** | **102** | **11** | **102** | **107** | **8** | |
| ***Fuel Type Total*** | | **410** | | | **150** | | **217** | | **10** | **781** |

**Italics denote school districts selected for CE-CERT's focused study*

CE-CERT conducted a preliminary statistical analysis to determine the number of buses and school districts needed to achieve the goal of the focused study. A preliminary power analysis was conducted on three representative dependent variables — emissions, mileage, and fuel economy — using variance estimates. The mean and variance for the emission estimates were taken from research previously conducted at CE-CERT. The mean and range for mileage were derived from consultation with Commission staff. The mean and standard deviation for fuel economy were calculated from data collected from the Antelope Valley school district.

The results for emissions, mileage and fuel economy are summarized in Table 2-2. These figures represent the estimated number of buses needed within each phase/fuel to have 95% confidence that the true population mean for the phase/fuel type lies within the given percentages. This indicates the number of buses necessary to characterize the population of all buses of a given phase/fuel type, and should not be confused with measurement error.

Note that these estimates assume simple random sampling. For example, such a sample of CNG buses would be conducted by randomly choosing the study vehicles from all CNG buses in the program. We improved on this by selecting from a limited number of school districts to reduce bus-to-bus variability from outside influences. In addition, with the type of analysis we have chosen, it is not required that the same number of samples be taken from each engine type.

**Table 2-2. Results of power analysis used to estimate number of buses required.**

| | 1% | 5% | 10% | 20% | 30% | 40% |
|---|---|---|---|---|---|---|
| ***Emissions*** | 1003 | 41 | 11 | 3 | 2 | 1 |
| ***Mileage*** | 278 | 12 | 3 | 1 | 1 | 1 |
| ***Fuel Consumption*** | 3600 | 144 | 36 | 9 | 4 | 3 |

It was decided that a total of nine buses of each phase/fuel type would be used for the focused study, resulting in the mean estimates accurate within about 5%. Due to the limited availability of facilities, emissions testing was limited to no more than three vehicles of each phase/fuel type. Thus, given our current estimate for emissions, the population mean is likely to be within 20% of the mean determined from testing three vehicles of each phase/fuel type. The estimated percentage accuracy would increase with fewer tests per bus, as indicated in Table 2-2.

It also was decided that the number of districts should be kept to a minimum in order to focus on bus differences without the influence of varying route types, urban/rural settings, elevations, and climates. Where possible, the buses in each phase/fuel type are divided evenly among three districts. These numbers rely on many assumptions and are used as a guide for determination of design adequacy because they are representative of the variables to be collected and were chosen to provide a conservative estimate for design efficiency. A detailed analysis of all variables for each phase/fuel type would require extensive analysis because of the large number of bus types involved.

Districts were selected based on: (a) the distribution of bus types, (b) geographic location, and (c) commitment and ability of the district to support the focused study. While many of the participating school districts in California meet the third criterion, consideration of the first two criteria resulted in the final selection of Antelope Valley, Clovis, and Kings Canyon school districts. Antelope Valley is located in northern Los Angeles County, and the other two districts are located near the southern end of the Sierra Nevada mountain range. Table 2-3 summarizes the bus selections and their distribution among the three participating school districts. Table 2-4 lists the individual buses included in the focused study.

**Table 2-3. Allocation of school bus and engine types for focused study.**

| | **CONTROL** | **PHASE 1** | | **PHASE 2** | | | **PHASE 3** | | **TOTAL** |
|---|---|---|---|---|---|---|---|---|---|
| **Fuel:** | Diesel | Diesel | Diesel | Methanol | CNG | Diesel | Electric | CNG | |
| Bus Manufacturer: | * | Crown Coach | Thomas | Carpenter | Blue Bird | Blue Bird | Blue Bird | Blue Bird | |
| Engine Model | * | Detroit Diesel 6V-92TA | Caterpillar 3116A | Detroit Diesel 6V92A | Tecogen 7000T | Caterpillar 3126 TA | - | John Deere Series 450 6081 HFN | |
| *Antelope Valley* | 6 | 0 | 6 | 3 | 9 | 0 | 1 | 3 | 28 |
| *Clovis* | 0 | 9 | 0 | 3 | 0 | 5 | 1 | 3 | 21 |
| *Kings Canyon* | 3 | 0 | 3 | 3 | 0 | 4 | 1 | 3 | 17 |
| **Total:** | 9 | 9 | 9 | 9 | 9 | 9 | 3 | 9 | 66 |

**Table 2-4. Listing of each bus in the focused study.**

| Fuel type/ phase | School district | District ID # | DAS # | Report code |
|---|---|---|---|---|
| ***Diesel Control*** | ***Antelope Valley*** | ANT--0022 | 00428 | DC-1-A |
| | | ANT--0974 | 00526 | DC-2-A |
| | | ANT--1074 | 00261 | DC-3-A |
| | | ANT--1275 | 00320 | DC-4-A |
| | | ANT--0572 | 00448 | DC-5-A |
| | | ANT--0672 | 00518 | DC-6-A |
| | ***Kings Canyon*** | KNY--0026 | 00425 | DC-7-K |
| | | KNY--0030 | 00507 | DC-8-K |
| | | KNY--0042 | 00009 | DC-9-K |
| ***Diesel Phase 1*** | ***Clovis*** | CLO--0021 | 01314 | D1-1-C |
| | | CLO--0023 | 01015 | D1-2-C |
| | | CLO--0024 | 00734 | D1-3-C |
| | | CLO--0025 | 00763 | D1-4-C |
| | | CLO--0026 | 00796 | D1-5-C |
| | | CLO--0027 | 01216 | D1-6-C |
| | | CLO--0029 | 00281 | D1-7-C |
| | | CLO--0030 | 00871 | D1-8-C |
| | | CLO--0031 | 00948 | D1-9-C |
| ***Diesel Phase 2*** | ***Antelope Valley*** | ANT--3492 | 00441 | D2-1-A |
| | | ANT--3592 | 00476 | D2-2-A |
| | | ANT--3692 | 00417 | D2-3-A |
| | | ANT--3792 | 00211 | D2-4-A |
| | | ANT--3892 | 00022 | D2-5-A |
| | | ANT--3992 | 00797 | D2-6-K |
| | ***Kings Canyon*** | KNY--0056 | 00099 | D2-7-K |
| | | KNY--0057 | 00358 | D2-8-K |
| | | KNY--0058 | 00450 | D2-9-K |

*continued next page*

**Table 2-4 (continued)**

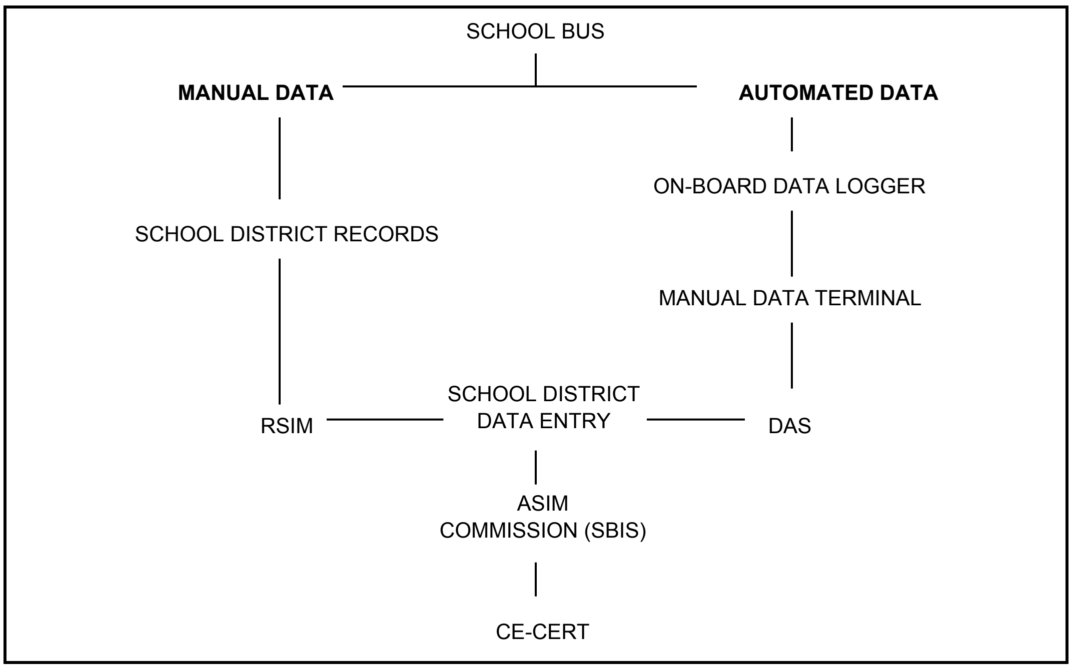
| Fuel type/ phase | School district | District ID # | DAS # | Report code |
|---|---|---|---|---|
| ***Diesel Phase 3*** | ***Clovis*** | CLO--0053 | 01979 | D3-1-C |
| | | CLO--0054 | 01936 | D3-2-C |
| | | CLO--0055 | 01810 | D3-3-C |
| | | CLO--0067 | 00243 | D3-4-C |
| | | CLO--0068 | 01942 | D3-5-C |
| | ***Kings Canyon*** | KNY--0004 | 01927 | D3-6-K |
| | | KNY--0012 | 02007 | D3-7-K |
| | | KNY--0024 | 02002 | D3-8-K |
| | | KNY--0029 | 02012 | D3-9-K |
| ***Meth Phase 2*** | ***Antelope Valley*** | ANT--2692 | 00511 | M2-1-A |
| | | ANT--2792 | 00019 | M2-2-A |
| | | ANT--2892 | 00123 | M2-3-A |
| | ***Clovis*** | CLO--0050 | 00980 | M2-4-C |
| | | CLO--0051 | 00248 | M2-5-C |
| | | CLO--0052 | 00947 | M2-6-C |
| | ***Kings Canyon*** | KNY--0019 | 00483 | M2-7-K |
| | | KNY--0033 | 00477 | M2-8-K |
| | | KNY--0034 | 00998 | M2-9-K |
| ***CNG Phase 2*** | ***Antelope Valley*** | ANT--0792 | 00977 | C2-1-A |
| | | ANT--0892 | 00870 | C2-2-A |
| | | ANT--0992 | 00987 | C2-3-A |
| | | ANT--1092 | 00253 | C2-4-A |
| | | ANT--1292 | 00118 | C2-5-A |
| | | ANT--1392 | 00181 | C2-6-A |
| | | ANT--1492 | 00185 | C2-7-A |
| | | ANT--1592 | 00007 | C2-8-A |
| | | ANT--1692 | 00489 | C2-9-A |
| ***CNG Phase 3*** | ***Antelope Valley*** | ANT--0296 | 01809 | C3-1-A |
| | | ANT--0396 | 01717 | C3-2-A |
| | | ANT--0696 | 01781 | C3-3-A |
| | ***Clovis*** | CLO--0071 | 01931 | C3-4-C |
| | | CLO--0073 | 00245 | C3-5-C |
| | | CLO--0074 | 01986 | C3-6-C |
| | ***Kings Canyon*** | KNY--0031 | 02001 | C3-7-K |
| | | KNY--0035 | 02008 | C3-8-K |
| | | KNY--0038 | 00263 | C3-9-K |

Not all of these buses were available for study during the entire period. Many of the Phase 3 buses were diverted temporarily to Atlanta in 1996 to provide transportation service during the Olympic Games. Other buses were out of service for various periods.

## 2.2 Data Collection

CE-CERT collected data from the participating school districts beginning April 1, 1996, and continuing through August, 1997. Data collection started at the school districts, with the drivers, mechanics, and on-board data loggers being the primary source of data. The drivers kept a daily log of all events that were recorded in EMDAILY.DBF. The mechanics accounted for all parts and labor costs that went into the maintenance and repairs for the buses recorded in EMPARTS.DBF, EMOTHER.DBF, and EMWOHEAD.DBF. The on-board dataloggers recorded the data found in TANKFILL.DBF and BASEDATA.DBF. These data were entered into the school districts database. From there, every two weeks the Commission downloaded the data. Once the files were at the Commission, CE-CERT could download the files for the purposes of compilation, analysis, and QA/QC. Appendix 1 provides a description of the data files that were received from the school districts. Figure 2-1 describes data collection methods and Commission distribution paths.

**Figure 2-1. The demonstration's data collection process.**




### 2.2.1 Reference Data

At the start of the program, the Commission completed a bus specification form (Appendix 2). This was updated as needed, such as in the case of a major modification to the engine or vehicle.

### 2.2.2 In-Service Data Collection

Data were collected on the buses to determine the impact of using alternative fuels on maintenance, fuel economy, exhaust emissions, and associated costs. All of the buses involved in the program are used in normal daily service by the school districts. It is important to note that for school buses, normal service may include operating over several routes per day and transporting students on field trips or to sporting events.

The school districts collect maintenance data and refueling information defined in this report. Table 2-5 lists all of the data items that were collected from the demonstration buses.

**Table 2-5. In-service data collection.**

| Type of Data | Collection Frequency | Data Item |
|---|---|---|
| ***Maintenance Data*** | For each work order: | Shop order number<br>Repair description<br>Type of maintenance<br>-Warranty<br>-Non-warranty<br>-Scheduled<br>-Unscheduled<br>-Road call<br>Labor hours<br>Date of repair<br>Odometer reading<br>Parts replaced – code<br>Parts cost<br>Work done – code<br>Date bus removed from service<br>Date bus returned to service |
| ***Fuel Data*** | Each time refueled: | Type of fuel<br>Amount of fuel<br>Odometer reading<br>Date |
| ***Bus route and operating cycle data*** | Each day: | Data from on-board data logger, select buses only |

Maintenance data and cost were collected to determine the reliability of the alternative fuel buses versus the conventional fuel buses. These data were coded to indicate whether the maintenance is warranty or non-warranty, scheduled, unscheduled or a road call. The Commission has provided the districts with maintenance log sheets to record parts, labor and cost for the work performed.

Operational data include daily miles traveled and refueling data. This information is recorded by the driver and/or fuel attendant, and is logged into the school districts database. From these data, fuel economy and cost are determined.

In addition to the manually recorded data, all of the buses in CE-CERT's focused study were equipped with dataloggers. The dataloggers were supplied by one of the Commission's subcontractors and were configured to monitor fuel consumption, engine RPM, bus speed, and mileage. Buses with electronic controls (Phase 1 and 2 methanol and Phase 1 diesel) had engine load and throttle monitored as well. Information from the data loggers was used to verify the manually recorded data. By collecting data while the vehicle is in operation, the dataloggers provide an accurate description of real driving habits and routes.

### 2.3 Quality Assurance/Quality Control

#### 2.3.1 QA/QC Logs

Initially, CE-CERT selected April 1, 1996, as the starting date of the demonstration's data analysis. It was believed that any anomalies found within the collected data could be quickly resolved prior to the next download. However, by July of 1996, CE-CERT discovered that a large number of the buses in the study did not consistently generate complete data. To keep track of the large amounts of missing data that accumulated with each download, CE-CERT added the *QA/QC Log* to the QCP. The *QA/QC Log* was an application developed by CE-CERT using Visual FoxPro 3.0. It was created as a means of keeping an up to date documentation of all of the problems encountered relating to the data. After the data were downloaded, the Visual FoxPro program sorted through the data for each bus during the two-week collection period and flagged the data according to the following conditions:

- no data
- no manual data
- no DAS data
- no maintenance data
- corrupt/missing data
- unusual data
- no daily log
- no coefficients
- data complete

The *QA/QC Log* also recorded any actions needed, the persons responsible for the action, the solution, and the current status.

An essential step in the use of the *QA/QC Log* was the construction of graphs that compared DAS and Manual data for each bus involved in the study. After going over each of the graphs with a Quality Assurance manager, CE-CERT constructed a list of observed problems and incorporated it into the *QA/QC Log*. Appendix 3 contains a copy of the *QA/QC Log.*

CE-CERT made full use of the *QA/QC Logs* until December 16, 1996. It must be noted that at this point, CE-CERT had yet to received a single complete data set from any of the buses in the demonstration. (A data set is defined as the entire data collected from the starting date to the present.) One school district had yet to send any data, while the other two were missing data sets from a total of ten buses.

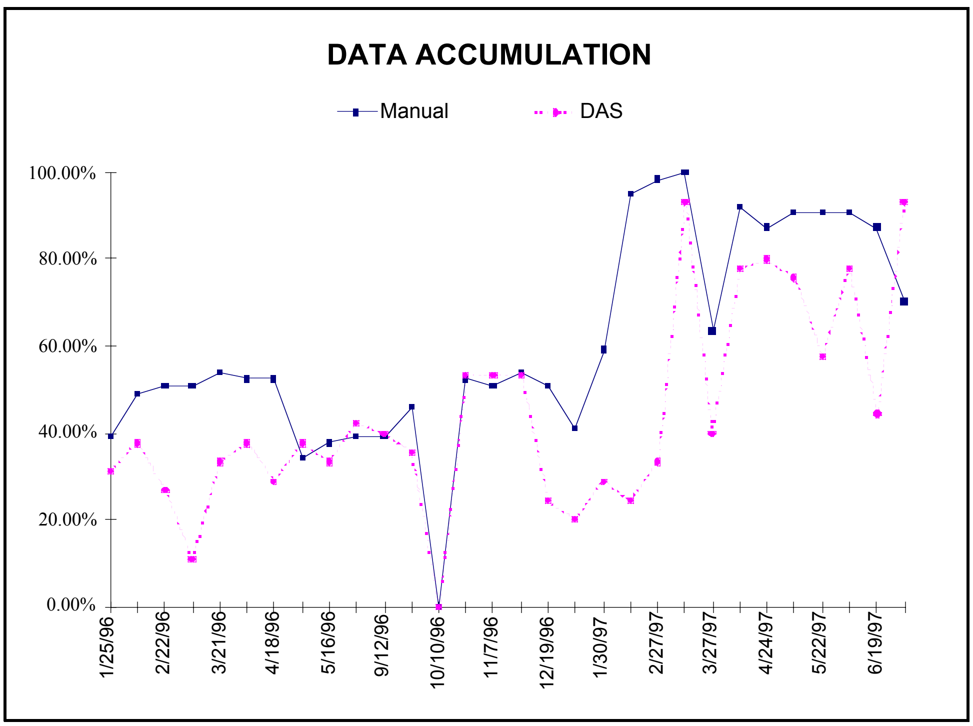
#### 2.3.2 File Status

In an effort to obtain a complete data set from a majority of the buses, the starting date of the demonstration's data analysis was rescheduled to January 1, 1997. At this time, CE-CERT found it necessary to break down the *QA/QC Log* to reduce the extensive amount of time it consumed. Each entry required the construction of DAS vs. Manual graphs, an analysis, an action, and delegation of responsibility. Instead of analyzing the data as soon as they came in, CE-CERT initially checked to see if any data were missing and immediately notified the school districts. Analysis of the data would be reserved until after CE-CERT was confident that all the data were coming in. Still using Visual FoxPro 3.0, CE-CERT accomplished this task by adding *File Status* to the QCP. After each download a *File Status* sheet was sent out to the school districts and the Commission. CE-CERT then went through the data and recorded any anomalies. These observations were relayed to all of the participating members of the demonstration program through electronic mail.

The *File Status* sheets were found to be more beneficial than the *QA/QC Logs*. The *File Status* method was used from January 1, 1997, until the completion of data collection. Appendix 4 contains a copy of *File Status* and the accompanying observations.

After the program's rescheduled start date of January 1, 1997, a dramatic increase in the quality and quantity of data was observed. Figure 2-2 illustrates the amount of data that CE-CERT expected to receive over the course of the program.

**Figure 2-2. Percentage of all data accumulated during the course of the demonstration.**




### 2.3.3 DAS vs. Manual Checks

Throughout the demonstration, CE-CERT constructed graphs of DAS vs. Manual Data for each of the buses involved in the study. Comparing the manually entered odometer readings and fuel records with the DAS, CE-CERT made a number of discoveries.

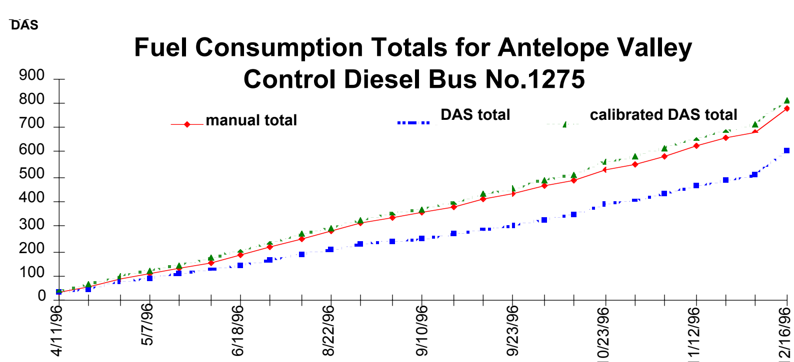
Primarily, most of the graphs showed DAS units that were either consistently low or high compared with their manual counterparts. This prompted CE-CERT to request a re-calibration of all of the liquid level DAS units.

After examining the DAS vs. Manual Data for Methanol Phase 2 buses, CE-CERT discovered that the fuel consumption from their DAS units, also called DDECs, appeared to be low by a factor of 2.30 compared with the Manual. This value was approximately equal to the conversion from methanol gallons to diesel gallons. CE-CERT contacted Detroit Diesel, the manufacturer of the DDEC, and discovered that the unit was originally designed for diesel fuel, not methanol. Keeping this in mind, CE-CERT simply used a diesel to methanol conversion factor to compare the DAS and Manual Data. Appendix 5 shows examples of the *DAS vs. Manual Checks.*

### 2.3.4 CE-CERT Re-Calibration

On December 16, 1996, CE-CERT recalibrated ten buses with liquid level sensors at the Antelope Valley School District. Ideally one would want to see the DAS calculation total match the manual recording total. Figure 2-3 shows the accumulation of fuel over a four month period for the old DAS calibration values (DAS Total), the new DAS calibration values (recalibrated DAS Total) and the manual data (Daily Total) for ANT 1275. Notice how the recalibrated DAS total is closer to the Daily Total than the DAS Total. The figure shows that the new coefficients were tracking manual fuel consumption more closely than the old coefficients. Similar graphs for the rest of the buses can be found in Appendix 5. Of the ten buses re-calibrated, CE-CERT only had DAS data for eight of the buses. Out of these eight, four buses showed improvements. Unfortunately four of the new coefficients are questionable and will require further investigation.

**Figure 2-3. The DAS Totals using the old coefficients and the re-calibrated coefficients compared with the Daily Total for ANT-1275 Control Diesel.**



### 2.4 Antelope Valley Interaction Study

Results of this data collection (which are discussed fully in Section 3) indicated that some of the Phase/Fuel types may experience variability based on route. To verify and quantify this effect, CE-CERT and ANT set up a small interaction study. A Phase 2 CNG, Phase 3 CNG, and Phase 3 diesel bus each was run over three routes. The main goal of this study was to determine whether there is an interaction between bus type and driver/route under normal operating conditions.

After consulting with Ken McCoy at Antelope Valley, it was decided to run the buses with each driver on his/her normal route rather than having drivers switching routes as well as buses. While it would be interesting to separate the driver and route effects, it was not possible during normal operation of the buses. This is because each driver has an assigned route or set of routes which he or she drives every day. The drivers are familiar with the stops, the roads, the traffic conditions, and the children who will be riding the bus. Separating the drivers from their normal routes would lead to driving patterns likely to be very different from normal operating conditions.

Three buses were selected from those available in the Antelope Valley School District and were in normal use in the district. All three buses were in good working order. The three drivers were selected because of their familiarity with the different bus types. The buses were randomly assigned to the drivers the first day, then rotated through the drivers until each driver had run each bus twice over the six days of the study. Because of some unscheduled events during completion of the routes, several of the routes had to be redone. This extended the number of days of the study. The study buses were not run on other routes during the course of the study to minimize the possibility of mechanical problems.

All buses were fully fueled the night before each test day. As soon as possible after completion of the routes the buses were refueled. Each driver kept a log of the starting mileage, ending mileage, and fuel used for each bus on each day. Each driver drove each of the three buses twice for a total of 6 days.

Results of this study are provided in Section 3.4.

# 3. Results and Discussion

Large amounts of statistically valid data were generated over the course of this project and were analyzed in three main areas.

1. The primary analysis examines overall cost per mile data for the Phase/Fuel types that were in use during this study.

2. A more detailed analysis was conducted on biweekly variability and bus/route/driver differences.

3. The third main area of analysis was on all available emissions data for the Phase/Fuel types in this study. The emissions data were generated at various times at the Los Angeles Metropolitan Transportation Authority dynamometer facilities; they were not collected as part of this study.

The results of these analyses indicated the need for a small-scale study to identify the interactive effects of route/driver on bus mileage. The approach for this study was described in Section 2.4, and results are discussed in Section 3.4.

## 3.1 Summary Data Analysis

The average cost per mile for fuel, maintenance, and repair was computed for each bus in the study over the entire data collection period. Data for this analysis were rejected if there was any reason to doubt their accuracy. The average for the study period was used to eliminate day to day variability, fuel variability, recording variability, and other factors to provide a single best overall estimate of the cost per mile for each bus. The average cost per mile for fuel, repair, and maintenance for each bus are presented in Table 3-1 a-c. In addition, total cost per mile and total cost per mile excluding scheduled maintenance were calculated and are presented in Table 3-1 d and e.

Because the buses are used on the same routes with the same drivers for much of the school year, the observed bus-to-bus variability in average cost per mile is probably an overestimate of the true variability within type. The cost per mile average for each bus represents the best estimate of the true cost per mile for that bus after averaging out the operating differences.

**Table 3-1a. Mean fuel cost per mile (cpm).**

| Bus | Type | Fuel cpm | Bus | Type | Fuel cpm | Bus | Type | Fuel cpm |
|---|---|---|---|---|---|---|---|---|
| ANT-0022 | Control Diesel | .127 | ANT-3492 | Diesel Phase 2 | .169 | CLO-0067 | Diesel Phase 3 | .128 |
| ANT-0296 | CNG Phase3 | .139 | ANT-3592 | Diesel Phase 2 | .149 | CLO-0068 | Diesel Phase 3 | .133 |
| ANT-0396 | CNG Phase3 | .148 | ANT-3692 | Diesel Phase 2 | .147 | CLO-0071 | CNG Phase 3 | .103 |
| ANT-0572 | Control Diesel | • | ANT-3792 | Diesel Phase 2 | .129 | CLO-0073 | CNG Phase 3 | .129 |
| ANT-0672 | Control Diesel | • | ANT-3892 | Diesel Phase 2 | .149 | CLO-0074 | CNG Phase 3 | .114 |
| ANT-0696 | CNG Phase3 | .138 | ANT-3992 | Diesel Phase 2 | .151 | KNY-0004 | Diesel Phase 3 | .164 |
| ANT-0792 | CNG Phase2 | .321 | CLO-0021 | Diesel Phase 1 | .216 | KNY-0012 | Diesel Phase 3 | .146 |
| ANT-0892 | CNG Phase2 | .280 | CLO-0023 | Diesel Phase 1 | .163 | KNY-0019 | Meth Phase 2 | .314 |
| ANT-0974 | Control Diesel | .157 | CLO-0024 | Diesel Phase 1 | .192 | KNY-0024 | Diesel Phase 3 | .148 |
| ANT-0992 | CNG Phase2 | .248 | CLO-0025 | Diesel Phase 1 | .173 | KNY-0026 | Control Diesel | .138 |
| ANT-1074 | Control Diesel | .155 | CLO-0026 | Diesel Phase 1 | .170 | KNY-0029 | Diesel Phase 3 | .153 |
| ANT-1092 | CNG Phase2 | .270 | CLO-0027 | Diesel Phase 1 | .173 | KNY-0030 | Control Diesel | .147 |
| ANT-1275 | Control Diesel | .126 | CLO-0029 | Diesel Phase 1 | .180 | KNY-0031 | CNG Phase 3 | .154 |
| ANT-1292 | CNG Phase2 | .233 | CLO-0030 | Diesel Phase 1 | .143 | KNY-0033 | Meth Phase 2 | .321 |
| ANT-1392 | CNG Phase2 | .219 | CLO-0031 | Diesel Phase 1 | .178 | KNY-0034 | Meth Phase 2 | .325 |
| ANT-1492 | CNG Phase2 | .271 | CLO-0050 | Meth Phase 2 | .289 | KNY-0035 | CNG Phase 3 | .177 |
| ANT-1592 | CNG Phase2 | .223 | CLO-0051 | Meth Phase 2 | .286 | KNY-0038 | CNG Phase 3 | .181 |
| ANT-1692 | CNG Phase2 | .278 | CLO-0052 | Meth Phase 2 | .289 | KNY-0042 | Control Diesel | .140 |
| ANT-2692 | Meth Phase2 | .329 | CLO-0053 | Diesel Phase 3 | .135 | KNY-0056 | Diesel Phase 2 | .156 |
| ANT-2792 | Meth Phase2 | .297 | CLO-0054 | Diesel Phase 3 | .140 | KNY-0057 | Diesel Phase 2 | .160 |
| ANT-2892 | Meth Phase2 | .284 | CLO-0055 | Diesel Phase 3 | .145 | KNY-0058 | Diesel Phase 2 | .155 |

**Table 3-1b Mean scheduled maintenance cost per mile (cpm).**

| Bus | Type | Maint cpm | Bus | Type | Maint cpm | Bus | Type | Maint cpm |
|---|---|---|---|---|---|---|---|---|
| ANT-0022 | Control Diesel | .155 | ANT-3492 | Diesel Phase 2 | .177 | CLO-0067 | Diesel Phase 3 | .053 |
| ANT-0296 | CNG Phase3 | .050 | ANT-3592 | Diesel Phase 2 | .063 | CLO-0068 | Diesel Phase 3 | .116 |
| ANT-0396 | CNG Phase3 | .040 | ANT-3692 | Diesel Phase 2 | .078 | CLO-0071 | CNG Phase 3 | .221 |
| ANT-0572 | Control Diesel | • | ANT-3792 | Diesel Phase 2 | .130 | CLO-0073 | CNG Phase 3 | .271 |
| ANT-0672 | Control Diesel | • | ANT-3892 | Diesel Phase 2 | .065 | CLO-0074 | CNG Phase 3 | .242 |
| ANT-0696 | CNG Phase3 | .030 | ANT-3992 | Diesel Phase 2 | .055 | KNY-0004 | Diesel Phase 3 | .061 |
| ANT-0792 | CNG Phase2 | .079 | CLO-0021 | Diesel Phase 1 | .278 | KNY-0012 | Diesel Phase 3 | .107 |
| ANT-0892 | CNG Phase2 | .101 | CLO-0023 | Diesel Phase 1 | .135 | KNY-0019 | Meth Phase 2 | .302 |
| ANT-0974 | Control Diesel | .043 | CLO-0024 | Diesel Phase 1 | .219 | KNY-0024 | Diesel Phase 3 | .087 |
| ANT-0992 | CNG Phase2 | .062 | CLO-0025 | Diesel Phase 1 | .131 | KNY-0026 | Control Diesel | .284 |
| ANT-1074 | Control Diesel | .052 | CLO-0026 | Diesel Phase 1 | .222 | KNY-0029 | Diesel Phase 3 | .109 |
| ANT-1092 | CNG Phase2 | .055 | CLO-0027 | Diesel Phase 1 | .302 | KNY-0030 | Control Diesel | .057 |
| ANT-1275 | Control Diesel | .061 | CLO-0029 | Diesel Phase 1 | .163 | KNY-0031 | CNG Phase 3 | .095 |
| ANT-1292 | CNG Phase2 | .109 | CLO-0030 | Diesel Phase 1 | .171 | KNY-0033 | Meth Phase 2 | .175 |
| ANT-1392 | CNG Phase2 | .170 | CLO-0031 | Diesel Phase 1 | .089 | KNY-0034 | Meth Phase 2 | .089 |
| ANT-1492 | CNG Phase2 | .078 | CLO-0050 | Meth Phase 2 | .209 | KNY-0035 | CNG Phase 3 | .173 |
| ANT-1592 | CNG Phase2 | .088 | CLO-0051 | Meth Phase 2 | .448 | KNY-0038 | CNG Phase 3 | .061 |
| ANT-1692 | CNG Phase2 | .089 | CLO-0052 | Meth Phase 2 | .335 | KNY-0042 | Control Diesel | .122 |
| ANT-2692 | Meth Phase2 | .078 | CLO-0053 | Diesel Phase 3 | .431 | KNY-0056 | Diesel Phase 2 | .084 |
| ANT-2792 | Meth Phase2 | .020 | CLO-0054 | Diesel Phase 3 | .140 | KNY-0057 | Diesel Phase 2 | .101 |
| ANT-2892 | Meth Phase2 | .067 | CLO-0055 | Diesel Phase 3 | .296 | KNY-0058 | Diesel Phase 2 | .149 |

**Table 3-1c Mean repair cost per mile (cpm).**

| Bus | Type | Repair cpm | Bus | Type | Repair cpm | Bus | Type | Repair cpm |
|---|---|---|---|---|---|---|---|---|
| ANT-0022 | Control Diesel | .142 | ANT-3492 | Diesel Phase 2 | .015 | CLO-0067 | Diesel Phase 3 | .088 |
| ANT-0296 | CNG Phase3 | .005 | ANT-3592 | Diesel Phase 2 | .062 | CLO-0068 | Diesel Phase 3 | .055 |
| ANT-0396 | CNG Phase3 | .019 | ANT-3692 | Diesel Phase 2 | .074 | CLO-0071 | CNG Phase 3 | .022 |
| ANT-0572 | Control Diesel | • | ANT-3792 | Diesel Phase 2 | .048 | CLO-0073 | CNG Phase 3 | 0.000 |
| ANT-0672 | Control Diesel | • | ANT-3892 | Diesel Phase 2 | .098 | CLO-0074 | CNG Phase 3 | .132 |
| ANT-0696 | CNG Phase3 | .104 | ANT-3992 | Diesel Phase 2 | .081 | KNY-0004 | Diesel Phase 3 | .007 |
| ANT-0792 | CNG Phase2 | .523 | CLO-0021 | Diesel Phase 1 | .050 | KNY-0012 | Diesel Phase 3 | .042 |
| ANT-0892 | CNG Phase2 | .313 | CLO-0023 | Diesel Phase 1 | .004 | KNY-0019 | Meth Phase 2 | .161 |
| ANT-0974 | Control Diesel | .083 | CLO-0024 | Diesel Phase 1 | .031 | KNY-0024 | Diesel Phase 3 | .044 |
| ANT-0992 | CNG Phase2 | .446 | CLO-0025 | Diesel Phase 1 | .196 | KNY-0026 | Control Diesel | .241 |
| ANT-1074 | Control Diesel | .062 | CLO-0026 | Diesel Phase 1 | .043 | KNY-0029 | Diesel Phase 3 | .040 |
| ANT-1092 | CNG Phase2 | .329 | CLO-0027 | Diesel Phase 1 | 0.000 | KNY-0030 | Control Diesel | .135 |
| ANT-1275 | Control Diesel | .235 | CLO-0029 | Diesel Phase 1 | .006 | KNY-0031 | CNG Phase 3 | .177 |
| ANT-1292 | CNG Phase2 | .312 | CLO-0030 | Diesel Phase 1 | .045 | KNY-0033 | Meth Phase 2 | .152 |
| ANT-1392 | CNG Phase2 | .249 | CLO-0031 | Diesel Phase 1 | .037 | KNY-0034 | Meth Phase 2 | .310 |
| ANT-1492 | CNG Phase2 | .188 | CLO-0050 | Meth Phase 2 | 0.000 | KNY-0035 | CNG Phase 3 | .071 |
| ANT-1592 | CNG Phase2 | .292 | CLO-0051 | Meth Phase 2 | .013 | KNY-0038 | CNG Phase 3 | .084 |
| ANT-1692 | CNG Phase2 | .452 | CLO-0052 | Meth Phase 2 | 0.000 | KNY-0042 | Control Diesel | .278 |
| ANT-2692 | Meth Phase2 | .155 | CLO-0053 | Diesel Phase 3 | .112 | KNY-0056 | Diesel Phase 2 | .198 |
| ANT-2792 | Meth Phase2 | .308 | CLO-0054 | Diesel Phase 3 | 0.000 | KNY-0057 | Diesel Phase 2 | .050 |
| ANT-2892 | Meth Phase2 | .085 | CLO-0055 | Diesel Phase 3 | .005 | KNY-0058 | Diesel Phase 2 | .197 |

## Table 3-1d Mean total cost per mile (cpm).

| Bus | Type | Fuel cpm | Bus | Type | Fuel cpm | Bus | Type | Fuel cpm |
|---|---|---|---|---|---|---|---|---|
| ANT-0022 | Control Diesel | .424 | ANT-3492 | Diesel Phase 2 | .360 | CLO-0067 | Diesel Phase 3 | .269 |
| ANT-0296 | CNG Phase3 | .195 | ANT-3592 | Diesel Phase 2 | .274 | CLO-0068 | Diesel Phase 3 | .304 |
| ANT-0396 | CNG Phase3 | .207 | ANT-3692 | Diesel Phase 2 | .299 | CLO-0071 | CNG Phase 3 | .347 |
| ANT-0572 | Control Diesel | • | ANT-3792 | Diesel Phase 2 | .307 | CLO-0073 | CNG Phase 3 | .399 |
| ANT-0672 | Control Diesel | • | ANT-3892 | Diesel Phase 2 | .312 | CLO-0074 | CNG Phase 3 | .487 |
| ANT-0696 | CNG Phase3 | .272 | ANT-3992 | Diesel Phase 2 | .287 | KNY-0004 | Diesel Phase 3 | .232 |
| ANT-0792 | CNG Phase2 | .923 | CLO-0021 | Diesel Phase 1 | .545 | KNY-0012 | Diesel Phase 3 | .296 |
| ANT-0892 | CNG Phase2 | .695 | CLO-0023 | Diesel Phase 1 | .302 | KNY-0019 | Meth Phase 2 | .778 |
| ANT-0974 | Control Diesel | .282 | CLO-0024 | Diesel Phase 1 | .442 | KNY-0024 | Diesel Phase 3 | .279 |
| ANT-0992 | CNG Phase2 | .756 | CLO-0025 | Diesel Phase 1 | .500 | KNY-0026 | Control Diesel | .664 |
| ANT-1074 | Control Diesel | .270 | CLO-0026 | Diesel Phase 1 | .435 | KNY-0029 | Diesel Phase 3 | .302 |
| ANT-1092 | CNG Phase2 | .654 | CLO-0027 | Diesel Phase 1 | .475 | KNY-0030 | Control Diesel | .339 |
| ANT-1275 | Control Diesel | .423 | CLO-0029 | Diesel Phase 1 | .350 | KNY-0031 | CNG Phase 3 | .426 |
| ANT-1292 | CNG Phase2 | .654 | CLO-0030 | Diesel Phase 1 | .359 | KNY-0033 | Meth Phase 2 | .649 |
| ANT-1392 | CNG Phase2 | .638 | CLO-0031 | Diesel Phase 1 | .304 | KNY-0034 | Meth Phase 2 | .724 |
| ANT-1492 | CNG Phase2 | .536 | CLO-0050 | Meth Phase 2 | .498 | KNY-0035 | CNG Phase 3 | .420 |
| ANT-1592 | CNG Phase2 | .603 | CLO-0051 | Meth Phase 2 | .747 | KNY-0038 | CNG Phase 3 | .326 |
| ANT-1692 | CNG Phase2 | .818 | CLO-0052 | Meth Phase 2 | .624 | KNY-0042 | Control Diesel | .540 |
| ANT-2692 | Meth Phase2 | .562 | CLO-0053 | Diesel Phase 3 | .677 | KNY-0056 | Diesel Phase 2 | .439 |
| ANT-2792 | Meth Phase2 | .625 | CLO-0054 | Diesel Phase 3 | .280 | KNY-0057 | Diesel Phase 2 | .311 |
| ANT-2892 | Meth Phase2 | .435 | CLO-0055 | Diesel Phase 3 | .446 | KNY-0058 | Diesel Phase 2 | .501 |

**Table 3-1e Mean total cost per mile (cpm) excluding scheduled maintenance.**

| Bus | Type | Fuel cpm | Bus | Type | Fuel cpm | Bus | Type | Fuel cpm |
|---|---|---|---|---|---|---|---|---|
| ANT-0022 | Control Diesel | .269 | ANT-3492 | Diesel Phase 2 | .184 | CLO-0067 | Diesel Phase 3 | .216 |
| ANT-0296 | CNG Phase3 | .144 | ANT-3592 | Diesel Phase 2 | .211 | CLO-0068 | Diesel Phase 3 | .188 |
| ANT-0396 | CNG Phase3 | .167 | ANT-3692 | Diesel Phase 2 | .221 | CLO-0071 | CNG Phase 3 | .126 |
| ANT-0572 | Control Diesel | • | ANT-3792 | Diesel Phase 2 | .177 | CLO-0073 | CNG Phase 3 | .129 |
| ANT-0672 | Control Diesel | • | ANT-3892 | Diesel Phase 2 | .247 | CLO-0074 | CNG Phase 3 | .246 |
| ANT-0696 | CNG Phase3 | .242 | ANT-3992 | Diesel Phase 2 | .232 | KNY-0004 | Diesel Phase 3 | .171 |
| ANT-0792 | CNG Phase2 | .843 | CLO-0021 | Diesel Phase 1 | .266 | KNY-0012 | Diesel Phase 3 | .189 |
| ANT-0892 | CNG Phase2 | .594 | CLO-0023 | Diesel Phase 1 | .167 | KNY-0019 | Meth Phase 2 | .476 |
| ANT-0974 | Control Diesel | .239 | CLO-0024 | Diesel Phase 1 | .223 | KNY-0024 | Diesel Phase 3 | .193 |
| ANT-0992 | CNG Phase2 | .694 | CLO-0025 | Diesel Phase 1 | .369 | KNY-0026 | Control Diesel | .379 |
| ANT-1074 | Control Diesel | .217 | CLO-0026 | Diesel Phase 1 | .213 | KNY-0029 | Diesel Phase 3 | .193 |
| ANT-1092 | CNG Phase2 | .598 | CLO-0027 | Diesel Phase 1 | .173 | KNY-0030 | Control Diesel | .282 |
| ANT-1275 | Control Diesel | .361 | CLO-0029 | Diesel Phase 1 | .187 | KNY-0031 | CNG Phase 3 | .331 |
| ANT-1292 | CNG Phase2 | .545 | CLO-0030 | Diesel Phase 1 | .188 | KNY-0033 | Meth Phase 2 | .474 |
| ANT-1392 | CNG Phase2 | .468 | CLO-0031 | Diesel Phase 1 | .215 | KNY-0034 | Meth Phase 2 | .635 |
| ANT-1492 | CNG Phase2 | .459 | CLO-0050 | Meth Phase 2 | .289 | KNY-0035 | CNG Phase 3 | .247 |
| ANT-1592 | CNG Phase2 | .515 | CLO-0051 | Meth Phase 2 | .299 | KNY-0038 | CNG Phase 3 | .265 |
| ANT-1692 | CNG Phase2 | .730 | CLO-0052 | Meth Phase 2 | .289 | KNY-0042 | Control Diesel | .418 |
| ANT-2692 | Meth Phase2 | .484 | CLO-0053 | Diesel Phase 3 | .247 | KNY-0056 | Diesel Phase 2 | .355 |
| ANT-2792 | Meth Phase2 | .605 | CLO-0054 | Diesel Phase 3 | .140 | KNY-0057 | Diesel Phase 2 | .210 |
| ANT-2892 | Meth Phase2 | .368 | CLO-0055 | Diesel Phase 3 | .151 | KNY-0058 | Diesel Phase 2 | .352 |

Actual fuel costs varied between districts and changed over time during this study. For this overall comparison, all fuel costs were assumed to be the same within fuel type The price of diesel was taken as $0.89/gallon, CNG was $0.66/therm, and methanol was calculated at

$0.55/gallon. Future analyses of operating costs can be performed by dividing the prevailing cost of the fuel by our standardized price. The result is then multiplied by our estimated fuel cost per mile for the bus type of interest. For example if the price of diesel rises to $1 per gallon, the adjusted fuel cost per mile is:

(current diesel price/standardized diesel price) * CPM from table.

For example, Bus ANT-0022 has a fuel cost per mile of $0.127 in Table 3-1a. If diesel fuel prices were to rise to $1, the cost per mile would be:

($1.00/$0.88)*$0.127=$0.144

### 3.1.1 Fuel Cost Per Mile

The average cost per mile in fuel for each bus is presented in Table 3-1a.

An Analysis of Variance (ANOVA) was conducted on the mean fuel cost per mile data from Table 3-1a. The ANOVA test is used to determine whether the observed differences in treatment (Phase/Fuel type in this case) are due to random chance. If the actual cost per mile for each Phase/Fuel type is the same, the means will not be significantly different. Any observed differences will be due only to random variation of the individual buses. For a detailed explanation of ANOVAs see D.C. Montgomery (1992). Significant differences (P<.0001) were found between Phase/Fuel types (Table 3-2), indicating that at least one Phase/Fuel type is significantly different from the rest. The mean fuel cost per mile with 95% error bars is presented in Table 3-3 and Figure 3-1. The Phase 2 Methanol buses are the most expensive, while the control Diesel buses are the least expensive.

**Table 3-2. ANOVA results for fuel cost per mile.**

**ANOVA Table for Fuel CPM**

| | DF | Sum of Squares | Mean Square | F-Value | P-Value |
|---|---|---|---|---|---|
| Phase/Fuel type | 6 | .232 | .039 | 91.835 | <.0001 |
| Residual | 54 | .023 | 4.205E-4 | | |

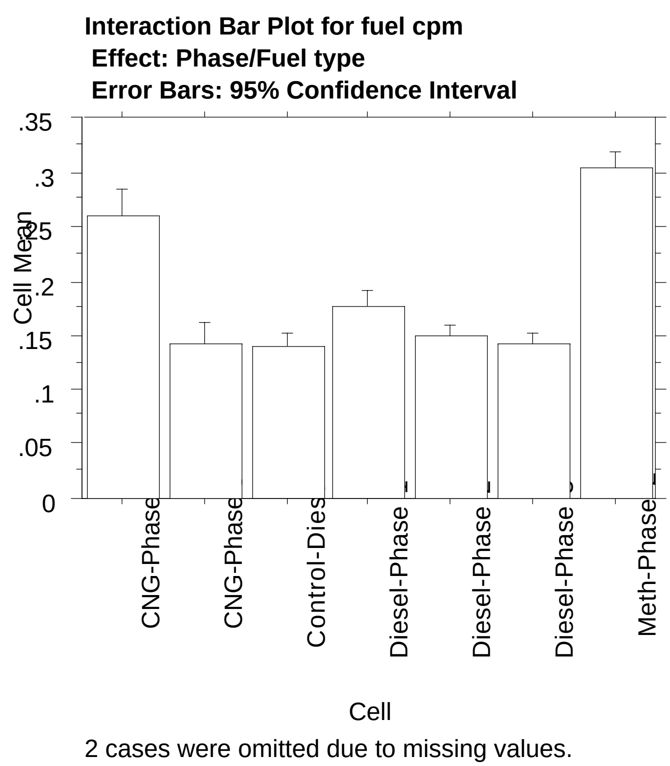
Model II estimate of between component variance: .004
2 cases were omitted due to missing values.

In the ANOVA table DF stands for Degrees of Freedom and is equal to the number of groups minus 1. Sum of Squares is the sum of the squared deviations of the observations from their group means. The Mean Square is defined as the Sum of Squares divided by the corresponding degrees of freedom. The F-value is the test statistic used to test whether the observed differences in group means is significant. The P-Value is the corresponding probability of getting an F-Value equal to or larger than the observed F-Value if there is no difference in groups. The P-Value of <.0001 found in this test indicates that there is less than one chance in 10,000 that the observed differences in cost per mile between Phase/Fuel types are due to chance. The large F-Value found in this test indicates that there is a very small chance that the bus types have the same average cost per mile.

**Table 3-3. Fuel cost per mile mean and standard deviation.**

| Phase/Fuel Type | Number of Buses Included | Mean Cost Per Mile for Fuel | Standard Deviation |
|---|---|---|---|
| Phase 2 Methanol | 9 | $0.304 | $0.018 |
| Phase 2 CNG | 9 | $0.260 | $0.033 |
| Phase 1 Diesel | 9 | $0.177 | $0.020 |
| Phase 2 Diesel | 9 | $0.152 | $0.011 |
| Phase 3 Diesel | 8 | $0.144 | $0.011 |
| Phase 3 CNG | 9 | $0.142 | $0.026 |
| Control Diesel | 7 | $0.142 | $0.012 |

**Figure 3-1 Bar chart of mean fuel cost per mile by Phase/Fuel types with 95% confidence intervals.**




### Mean Comparisons

Significant differences in fuel cost per mile were found in the ANOVA, so the Duncans New Multiple range test was used to test for differences between all pairs of Phase/Fuel types. These results are presented in Table 3-4 with Phase/Fuel types that are not significantly different having the same letter grouping. Because the paired comparison test is applied to all possible pairs of tests, it is designed to have an over all error rate of 5% for a set of tests. This makes the test good for grouping of treatments, but not as powerful for testing for differences between specific pairs or groups of treatments. The Duncans New Multiple Range test identified four groups as shown in Table 3-4, Group A being the most cost-effective and D the least.

**Table 3-4 Duncans New Multiple range test results for fuel cost per mile.**

| Phase/Fuel Type | Mean Cost Per Mile for Fuel | Grouping Code |
|---|---|---|
| Phase 2 Methanol | $0.304 | D |
| Phase 2 CNG | $0.260 | C |
| Phase 1 Diesel | $0.177 | B |
| Phase 2 Diesel | $0.152 | A |
| Phase 3 Diesel | $0.144 | A |
| Phase 3 CNG | $0.142 | A |
| Control Diesel | $0.142 | A |

Where specific treatment mean comparisons are of interest, orthogonal contrasts are more powerful for detecting differences between specific pairs or groups of means. The contrasts work by partitioning the Phase/Fuel Sum of Squares in the ANOVA so the number of comparisons that can be made is limited to the number of degrees of freedom (6). In addition, the contrasts must be set up prior to running the ANOVA. The tests run for this analysis were:

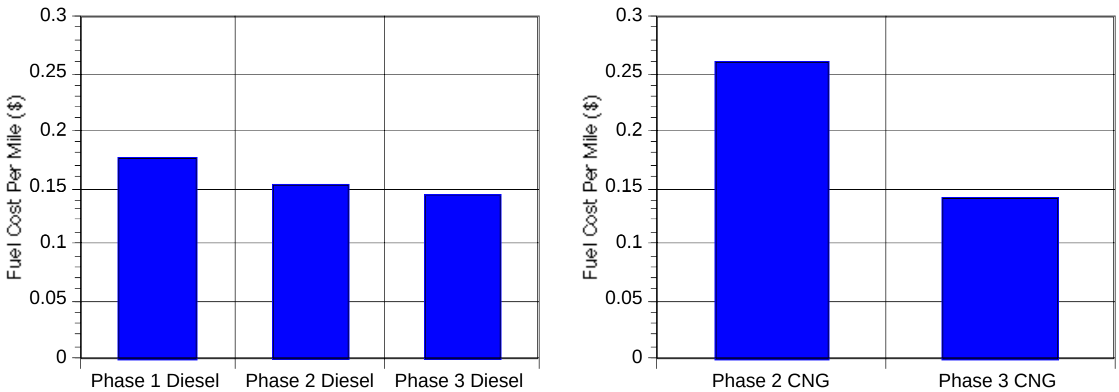
1. Phase 1 Diesel vs. Phase 2 Diesel
2. Phase 1 Diesel vs. Phase 3 Diesel
3. Phase 2 Diesel vs. Phase 3 Diesel
4. Phase 2 CNG vs. Phase 3 CNG
5. Phase 3 Diesel vs Phase 3 CNG.

The findings were as follows:

1. Phase 1 Diesel vs. Phase 2 Diesel: F-value = 6.584 P-value = 0.0131 (Significant difference)
2. Phase 1 Diesel vs. Phase 3 Diesel: F-value = 11.574 P-value = 0.0013 (Highly significant difference)
3. Phase 2 Diesel vs. Phase 3 Diesel: F-value = 0.699 P-value = 0.4067 (No significant difference)

The average fuel cost per mile decreased for the diesel buses with each successive phase of the Safe School Bus Program (Figure 3-2a). Phase 2 and 3 Diesel buses have a significantly lower fuel cost per mile than the Phase 1 Diesel buses. While the Phase 3 buses have a lower fuel cost per mile than the Phase 2 Diesel buses, the difference is not statistically significant.

**Figure 3-2 Mean fuel cost per mile for a)Phase 1,2, and 3 Diesel and b) Phase 2 and 3 CNG.**




4. Phase 2 CNG vs. Phase 3 CNG: F-value = 148.287 P-value = 0.0001

The average fuel cost per mile decreased considerably for the CNG buses from Phase 2 to Phase 3 (Figure 3-2b). The third phase of the Safe School Bus Program produced fuel cost per mile numbers for the CNG buses that were closely comparable to those of the diesel buses. The last contrast was to test for a difference in mean fuel cost per mile between the Phase 3 Diesel and the Phase 3 CNG buses. No significant difference was found.

5. Phase 3 Diesel vs. Phase 3 CNG: F-value = 0.015 P-value = 0.9018

Bus-to-bus variability of fuel cost per mile is of interest because it is an indication of how meaningful the results were for each Phase/Fuel type. High within-group variability would reduce the usefulness of future projections of associated costs. High within-group variability also could be indicative of Phase/Fuel types that are more sensitive to driver and route differences. The F-ratio test (Steel and Torrie, 1991) for differences in variance between groups is a one-tailed test in which the variance of the more variable group is divided by the variance of the lower variability group. The ratio is compared with a standard F table having n1-1 and n2-1 degrees of freedom. In this case we do not have specific group comparisons in mind in advance; the probabilities should not be considered exact, but should be used to identify groups for more detailed analysis using the biweekly data.

Comparing the most variable group, the Phase 3 CNG, against the least variable, the Methanol Phase 2, we calculate our variance ratio (variance = Standard Deviation squared) as 0.000676/0.000081 = 8.35 with 8 and 7 degrees of freedom. This ratio is significant at 1% (.01), indicating that the CNG Phase 3 buses are significantly more variable in fuel cost per mile than the Diesel Phase 3 buses. This would imply that the CNG bus cost-effectiveness may depend on route and driver characteristics to a greater extent than the other bus types.

The next-lowest variability group was the Phase 2 Diesel buses; the variance ratio is calculated as 0.000676/0.000121 = 5.59 with 8 and 8 degrees of freedom. This value is significant at the 5% (.05) level of significance. The ratio for Phase 3 CNG vs. Control Diesel was 4.69, which also was significant at the 5% level of confidence. No other ratio was significant. This indicates that there are significant differences in fuel CPM between the most variable buses and the least variable, but overall the variability from bus to bus is similar between most groups.

The Phase 3 CNG bus results were examined in more detail with an ANOVA to test for mean differences among the three districts. Significant differences were found (Table 3-5) between districts, with Kings Canyon having the highest cost per mile (Figure 3-3). These results indicate that the Phase 3 CNG fuel cost per mile results were more variable from bus to bus than the other types because of differences between the districts. Means separation tests indicated that the Kings Canyon Phase 3 CNG buses had significantly higher fuel cost per mile than the Clovis buses, because of greater fuel consumption per mile.

One possible explanation for the lower miles per therm of the KNY Phase 3 CNG buses is lower fuel quality. With the current data it is not possible to statistically determine the validity of this hypothesis because all of the Phase 2 CNG buses are located in the Antelope Valley district and thus can not be used to determine whether this is unique to the Phase 3 CNG buses. The effect of fuel quality will be examined in greater detail in Section 3.2.1.

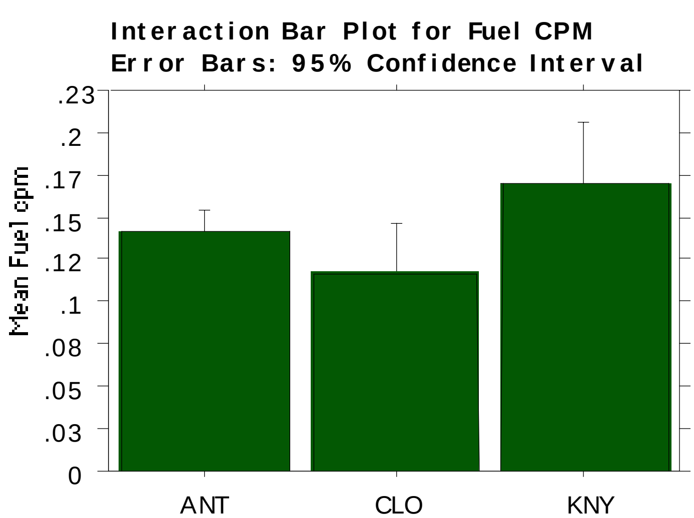
**Table 3-5 ANOVA results for District differences on fuel cost per mile for Phase 3 CNG buses only.**

**ANOVA Table for fuel CPM**
**Inclusion criteria: Criteria 1 from bus mileage final short**

| | DF | Sum of Squares | Mean Square | F-Value | P-Value |
|---|---|---|---|---|---|
| District | 2 | .005 | .002 | 17.252 | .0033 |
| Residual | 6 | .001 | 1.329E-4 | | |

Model II estimate of between component variance: .001

**Figure 3-3. Mean cost per mile by district for Phase 3 CNG buses.**




For other bus types there was no significant difference between the districts in fuel cost per mile. For the Phase 3 CNG buses the variability within each district was low, but the districts were all significantly different from one another in mean fuel cost per mile.

### 3.1.2 Maintenance Cost Per Mile

For our analysis all scheduled work was counted as maintenance, while the unscheduled work was included in the repair data. Some of the warranty work did not have a dollar amount recorded. As a result, the figures for maintenance cost are as comprehensive as possible, but not all maintenance expenses were captured in the data collection process. An ANOVA was conducted on the mean maintenance cost per mile data from Table 3-1b. No significant differences ($p=0.1382$) were found between Phase/Fuel types (Table 3-6), indicating that no Phase/Fuel type is significantly different from the rest. The mean maintenance cost per mile with 95% error bars is presented in Table 3-7 and Figure 3-4.

**Table 3-6. ANOVA results for maintenance cost per mile.**

**ANOVA Table for maint. cpm**

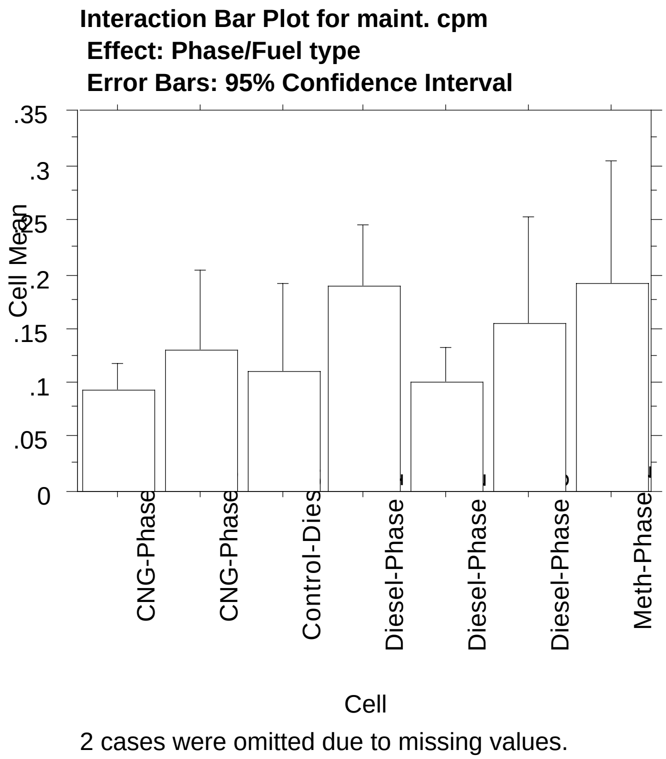
| | DF | Sum of Squares | Mean Square | F-Value | P-Value |
|---|---|---|---|---|---|
| Phase/Fuel type | 6 | .090 | .015 | 1.702 | .1382 |
| Residual | 54 | .476 | .009 | | |

Model II estimate of between component variance: .001
2 cases were omitted due to missing values.

**Table 3-7. Maintenance cost per mile mean and standard deviation.**

| Phase/Fuel Type | Number of Buses Included | Mean Cost Per Mile for Maintenance | Standard Deviation |
|---|---|---|---|
| Phase 2 Methanol | 9 | $0.191 | $0.145 |
| Phase 1 Diesel | 9 | $0.190 | $0.071 |
| Phase 3 Diesel | 9 | $0.155 | $0.125 |
| Phase 3 CNG | 9 | $0.131 | $0.095 |
| Control Diesel | 7 | $0.111 | $0.087 |
| Phase 2 Diesel | 9 | $0.100 | $0.043 |
| Phase 2 CNG | 9 | $0.092 | $0.034 |

**Figure 3-4 Bar chart of mean maintenance cost per mile by phase/fuel types with 95% confidence intervals.**




### Mean Comparisons

No significant differences in maintenance cost per mile were found in the ANOVA, so no means tests were conducted on the maintenance cost per mile results. All bus types are in the same group (Table 3-8).

**Table 3-8 Duncans New Multiple range test results for maintenance cost per mile.**

| Phase/Fuel Type | Mean Cost Per Mile for Maintenance | Grouping Code |
|---|---|---|
| Phase 2 Methanol | $0.191 | A |
| Phase 1 Diesel | $0.190 | A |
| Phase 3 Diesel | $0.155 | A |
| Phase 3 CNG | $0.131 | A |
| Control Diesel | $0.111 | A |
| Phase 2 Diesel | $0.100 | A |
| Phase 2 CNG | $0.092 | A |

Bus-to-bus variability of maintenance cost per mile is of interest because it is an indication of how variable the results were for each Phase/Fuel type. High within-group variability would reduce the usefulness of future projections of associated costs. High within-group variability also could be indicative of Phase/Fuel types that are more sensitive to driver and route differences.

### 3.1.3 Repair Cost Per Mile

Repair costs were calculated from all unscheduled expenditures. As with the maintenance data, some of the warranty repairs did not have cost data available. An ANOVA was conducted on the mean repair cost per mile data from Table 3-1c. Significant differences ($p<.0009$) were found between Phase/Fuel types (Table 3-9), indicating that at least one Phase/Fuel type is significantly different from the rest. The mean repair cost per mile with 95% error bars is presented in Table 3-10 and Figure 3-5. The Phase 2 CNG buses have the highest cost per mile while the Phase 3 Diesel have the lowest repair cost per mile.

**Table 3-9. ANOVA results for repair cost per mile.**

**ANOVA Table for Repair CPM**

| | DF | Sum of Squares | Mean Square | F-Value | P-Value |
|---|---|---|---|---|---|
| Phase/Fuel type | 6 | .604 | .101 | 15.363 | <.0001 |
| Residual | 54 | .354 | .007 | | |

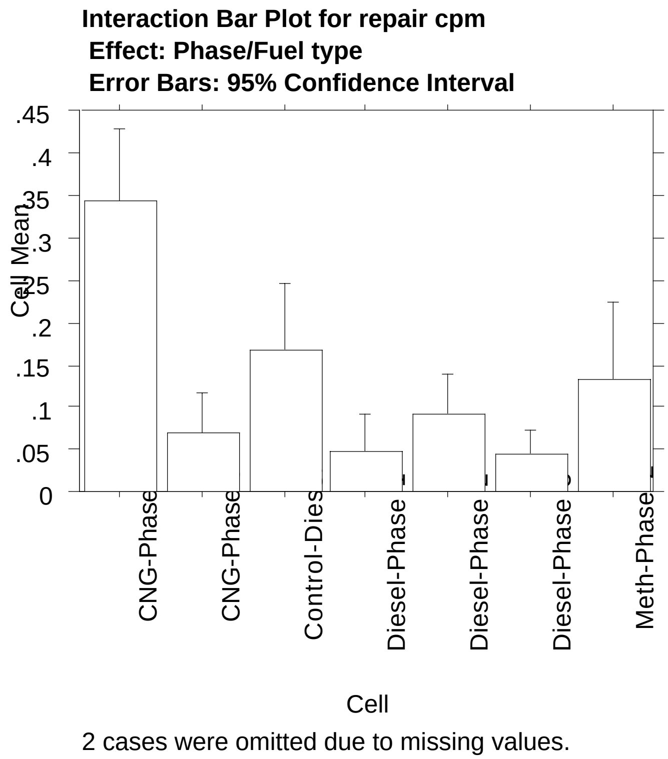
Model II estimate of between component variance: .011

2 cases were omitted due to missing values.

**Table 3-10. Repair cost per mile mean and standard deviation.**

| Phase/Fuel Type | Number of Buses Included | Mean Cost Per Mile for Repairs | Standard Deviation |
|---|---|---|---|
| Phase 2 CNG | 9 | $0.345 | $0.107 |
| Control Diesel | 7 | $0.168 | $0.084 |
| Phase 2 Methanol | 9 | $0.132 | $0.120 |
| Phase 2 Diesel | 9 | $0.091 | $0.065 |
| Phase 3 CNG | 9 | $0.068 | $0.062 |
| Phase 1 Diesel | 9 | $0.046 | $0.059 |
| Phase 3 Diesel | 9 | $0.044 | $0.038 |

**Figure 3-5. Bar chart of mean repair cost per mile by phase/fuel types with 95% Confidence Intervals.**




## Mean Comparisons

Significant differences in repair cost per mile were found in the ANOVA, so the Duncans New Multiple range test was used to test for differences between all pairs of Phase/Fuel types. These results are presented in Table 3-11 with Phase/Fuel types that are not significantly different having the same letter grouping. Because the paired comparison test is applied to all possible pairs of tests, it is designed to have an overall error rate of 5% for a set of tests. This makes the test good for grouping of treatments, but not as powerful for testing for differences between specific pairs or groups of treatments. The Duncans New Multiple range test identified four groups with some overlap.

**Table 3-11 Duncans New Multiple range test results for repair cost per mile.**

| Phase/Fuel Type | Mean Cost Per Mile for Repair | Grouping Code |
|---|---|---|
| Phase 2 CNG | $0.345 | D |
| Control Diesel | $0.168 | C |
| Phase 2 Methanol | $0.132 | B C |
| Phase 2 Diesel | $0.091 | A B C |
| Phase 3 CNG | $0.068 | A B |
| Phase 1 Diesel | $0.046 | A |
| Phase 3 Diesel | $0.044 | A |

The tests run for this analysis were:

1. Phase 1 Diesel vs. Phase 2 Diesel
2. Phase 1 Diesel vs. Phase 3 Diesel
3. Phase 2 Diesel vs. Phase 3 Diesel
4. Phase 2 CNG vs. Phase 3 CNG
5. Phase 3 Diesel vs. Phase 3 CNG.

Results of these tests were as follows:

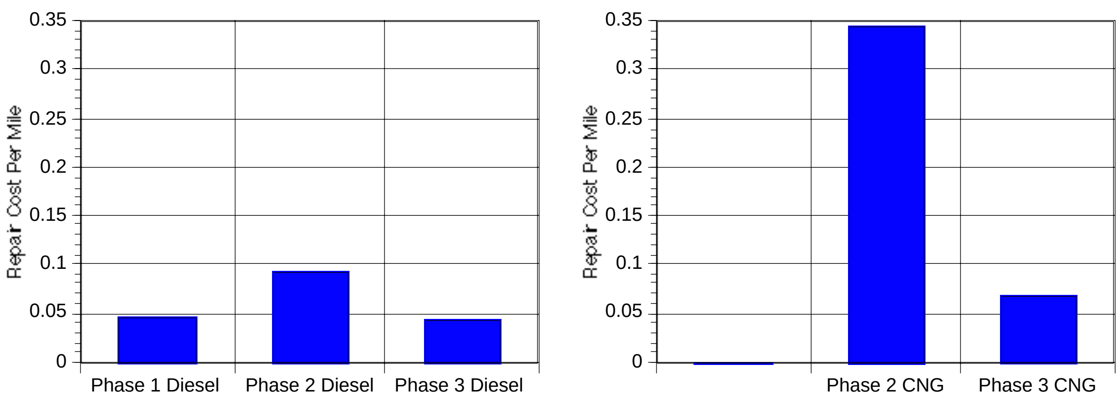
1. Phase 1 Diesel vs. Phase 2 Diesel: F-value = 1.429 P-value = 0. 2372 (No significant difference)

2. Phase 1 Diesel vs. Phase 3 Diesel: F-value = 0.003 P-value = 0. 9556 (No significant difference)

3. Phase 2 Diesel vs. Phase 3 Diesel: F-value = 1.566 P-value = 0. 2162 (No significant difference)

The average repair cost per mile was not significantly different as shown above for the diesel buses between each successive phase of the Safe School Bus Program (Figure 3-6a).

**Figure 3-6. Mean repair cost per mile for a)Phase 1,2, and 3 diesel and b) Phase 2 and 3 CNG.**




4. Phase 2 CNG vs. Phase 3 CNG: F-value = 52.587 P-value = 0.0001 (Highly significant differences between CNG 2 and 3)

The average repair cost per mile decreased significantly for the CNG buses from Phase 2 to Phase 3 (Figure 3-6b). The third phase of the Safe School Bus Program produced repair cost per mile numbers for the CNG buses that were comparable to those of the diesel buses. The last contrast was to test for a difference in mean repair cost per mile between the Phase 3 Diesel and the Phase 3 CNG buses. No significant difference was found.

5. Phase 3 Diesel vs. Phase 3 CNG: F-value = 0.417 P-value = 0. 5212 (No significant difference)

Bus-to-bus variability of repair cost per mile is of interest because it is an indication of how variable the results were for each Phase/Fuel type. High within-group variability would reduce the usefulness of future projections of associated costs. High within group variability also could be indicative of Phase/Fuel types which are more sensitive to driver and route differences.

### 3.1.4 Total Cost Per Mile

An ANOVA was conducted on the mean total cost per mile data from Table 3-1d. Significant differences ($p<.0208$) were found between Phase/Fuel types (Table 3-12), indicating that at least one Phase/Fuel type is significantly different from the rest. The mean total cost per mile with 95% error bars is presented in Table 3-13 and Figure 3-7.

**Table 3-12. ANOVA results for total cost per mile.**

**ANOVA Table for total cpm**

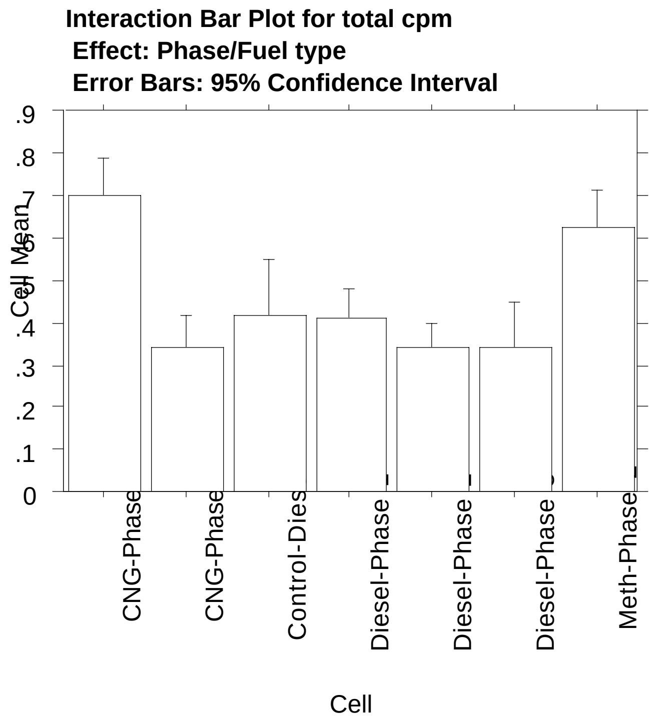
| | DF | Sum of Squares | Mean Square | F-Value | P-Value |
|---|---|---|---|---|---|
| Phase/Fuel type | 6 | 1.160 | .193 | 15.288 | <.0001 |
| Residual | 54 | .683 | .013 | | |

Model II estimate of between component variance: .021
2 cases were omitted due to missing values.

**Table 3-13. Total cost per mile mean and standard deviation.**

| Phase/Fuel Type | Number of Buses Included | Mean Total Cost Per Mile | Standard Deviation |
|---|---|---|---|
| Phase 2 CNG | 9 | $0.697 | $0.118 |
| Phase 2 Methanol | 9 | $0.627 | $0.114 |
| Control Diesel | 9 | $0.420 | $0.143 |
| Phase 1 Diesel | 9 | $0.412 | $0.088 |
| Phase 2 Diesel | 9 | $0.343 | $0.077 |
| Phase 3 Diesel | 9 | $0.343 | $0.139 |
| Phase 3 CNG | 7 | $0.342 | $0.102 |

**Figure 3-7. Bar chart of mean total cost per mile by phase/fuel types with 95% confidence intervals.**




2 cases were omitted due to missing values.

## Mean Comparisons

Significant differences in total cost per mile were found in the ANOVA, so the Duncans New Multiple range test was used to test for differences between all pairs of Phase/Fuel types. These results are presented in Table 3-14 with Phase/Fuel types that are not significantly different having the same letter grouping. Because the paired comparison test is applied to all possible pairs of tests, it is designed to have an overall error rate of 5% for a set of tests. This makes the test good for grouping of treatments, but not as powerful for testing for differences between specific pairs or groups of treatments. The Duncans New Multiple Range test identified two groups.

**Table 3-14 Duncans New Multiple range test results for total cost per mile.**

| Phase/Fuel Type | Mean Cost Per Mile for Total | Grouping Code |
|---|---|---|
| Phase 2 CNG | $0.697 | B |
| Phase 2 Methanol | $0.627 | B |
| Control Diesel | $0.420 | A |
| Phase 1 Diesel | $0.412 | A |
| Phase 3 Diesel | $0.343 | A |
| Phase 2 Diesel | $0.343 | A |
| Phase 3 CNG | $0.342 | A |

The tests run for this analysis were:

1. Phase 1 Diesel vs. Phase 2 Diesel
2. Phase 1 Diesel vs. Phase 3 Diesel
3. Phase 2 Diesel vs. Phase 3 Diesel
4. Phase 2 CNG vs. Phase 3 CNG
5. Phase 3 Diesel vs. Phase 3 CNG.

Results were as follows:

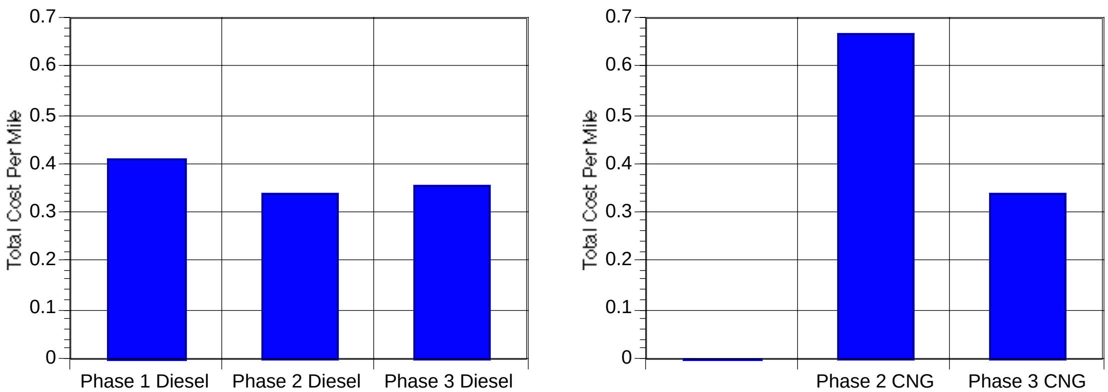
1. Phase 1 Diesel vs. Phase 2 Diesel: F-value = 1.700 P-value = 0. 1974 (No significant difference)

2. Phase 1 Diesel vs. Phase 3 Diesel: F-value = 1.724 P-value = 0. 1948 (No significant difference)

3. Phase 2 Diesel vs. Phase 3 Diesel: F-value = 0.008 P-value = 0. 9929 (No significant difference)

The average total cost per mile decreased from the first phase for the diesel buses in phases 2 and 3. (Figure 3-8a). Phase 2 and 3 Diesel buses have a significantly lower total cost per mile than the Phase 1 Diesel buses. While the Phase 3 buses have a lower total cost per mile than the Phase 2 Diesel buses, the difference is not statistically significant.

**Figure 3-8. Mean total cost per mile for a)Phase 1,2, and 3 diesel and b) Phase 2 and 3 CNG.**




4. Phase 2 CNG vs. Phase 3 CNG: F-value = 44.921 P-value = 0. 0001 (Highly significant difference between Phase 2 and 3)

The average total cost per mile decreased considerably for the CNG buses from Phase 2 to Phase 3 (Figure 3-8b). The third phase of the Safe School Bus Program produced total cost per mile numbers for the CNG buses comparable to those of the diesel buses. The last contrast was to test for a difference in mean total cost per mile between the Phase 3 Diesel and the Phase 3 CNG buses. No significant difference was found.

5. Phase 3 Diesel vs. Phase 3 CNG: F-value = 0.001 P-value = 0. 9899 (No significant difference)

Bus-to-bus variability of total cost per mile is of interest because it is an indication of how variable the results were for each Phase/Fuel type. High within-group variability would reduce the usefulness of future projections of associated costs. High within group variability could also be indicative of Phase/Fuel types which are more sensitive to driver and route differences.

### 3.1.5 Total Cost Per Mile Excluding Maintenance

No significant differences in maintenance cost per mile were found in Section 3.1.2, but there was a high bus-to-bus variability in maintenance within the Phase/Fuel groups. Total cost per mile was analyzed excluding maintenance to eliminate a major source of variability. An ANOVA was conducted on the mean total cost per mile excluding maintenance data from Table 3-1e. Significant differences ($p<.0208$) were found between Phase/Fuel types (Table 3-15), indicating that at least one Phase/Fuel type is significantly different from the rest. The mean total cost per mile with 95% error bars is presented in Table 3-16 and Figure 3-9. The Phase 2 CNG buses are the most expensive while the Phase 3 Diesel buses are the least expensive.

**Table 3-15. ANOVA results for total cost per mile.**

**ANOVA Table for tot cpm less maint**

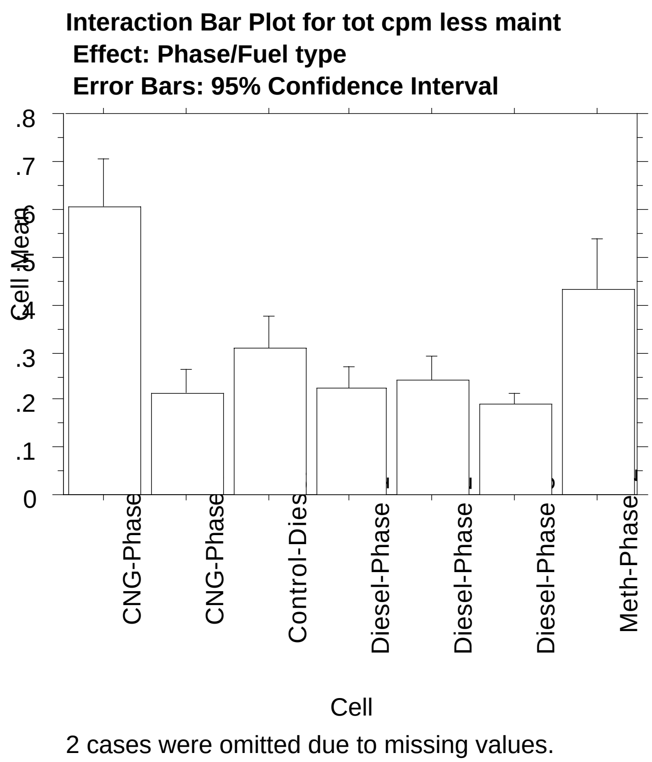
| | DF | Sum of Squares | Mean Square | F-Value | P-Value |
|---|---|---|---|---|---|
| Phase/Fuel type | 6 | 1.256 | .209 | 26.702 | <.0001 |
| Residual | 54 | .423 | .008 | | |

Model II estimate of between component variance: .023
2 cases were omitted due to missing values.

**Table 3-16. Total cost excluding maintenance per mile mean and standard deviation.**

| Phase/Fuel Type | Number of Buses Included | Mean Total Cost Per Mile | Standard Deviation |
|---|---|---|---|
| Phase 2 CNG | 9 | $0.605 | $0.129 |
| Phase 2 Methanol | 9 | $0.435 | $0.132 |
| Control Diesel | 7 | $0.309 | $0.132 |
| Phase 2 Diesel | 9 | $0.243 | $0.066 |
| Phase 1 Diesel | 9 | $0.222 | $0.063 |
| Phase 3 CNG | 9 | $0.211 | $0.072 |
| Phase 3 Diesel | 9 | $0.187 | $0.032 |

**Figure 3-9 Bar chart of mean total cost per mile excluding maintenance by phase/fuel types with 95% confidence intervals.**




### Mean Comparisons

Significant differences in total cost per mile excluding maintenance were found in the ANOVA, so the Duncans New Multiple range test was used to test for differences between all pairs of Phase/Fuel types. These results are presented in Table 3-17, with Phase/Fuel types that are not significantly different having the same letter grouping. Because the paired comparison test is applied to all possible pairs of tests, it is designed to have an over-all error rate of 5% for a set of tests. This makes the test good for grouping of treatments, but not as powerful for testing for differences between specific pairs or groups of treatments. The Duncans New Multiple Range test identified four groups as shown in Table 3-17.

The tests run for this analysis were:

1. Phase 1 Diesel vs. Phase 2 Diesel
2. Phase 1 Diesel vs. Phase 3 Diesel
3. Phase 2 Diesel vs. Phase 3 Diesel
4. Phase 2 CNG vs. Phase 3 CNG
5. Phase 3 Diesel vs. Phase 3 CNG.

Results were as follows:

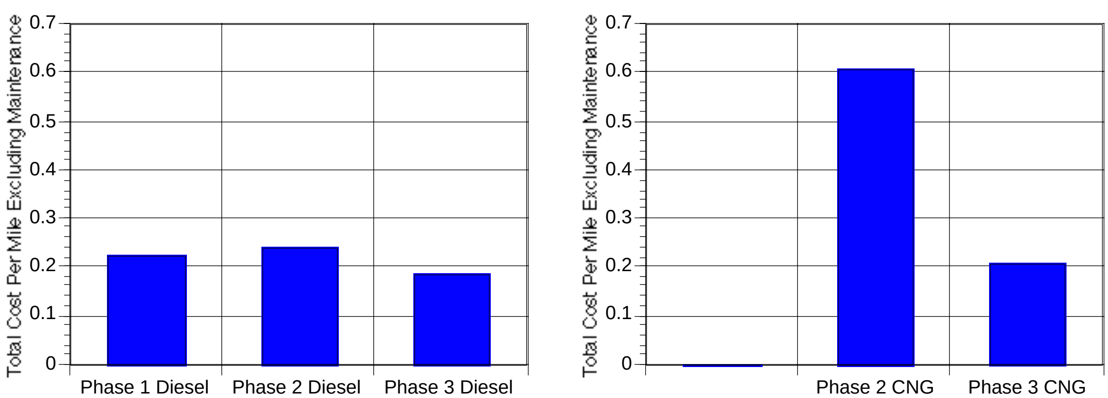
**Table 3-17. Duncans New Multiple range test results for total cost per mile excluding maintenance.**

| Phase/Fuel Type | Mean Cost Per Mile for Total Excluding Maint. | Grouping Code |
|---|---|---|
| Phase 2 CNG | $0.605 | D |
| Phase 2 Methanol | $0.435 | C |
| Control Diesel | $0.309 | B |
| Phase 2 Diesel | $0.243 | A B |
| Phase 1 Diesel | $0.222 | A B |
| Phase 3 CNG | $0.211 | A |
| Phase 3 Diesel | $0.187 | A |

1. Phase 1 Diesel vs. Phase 2 Diesel: F-value = 0.250 P-value = 0. 6188 (No significant difference)
2. Phase 1 Diesel vs. Phase 3 Diesel: F-value = 0.694 P-value = 0. 4084 (No significant difference)
3. Phase 2 Diesel vs. Phase 3 Diesel: F-value = 1.779 P-value = 0. 1879 (No significant difference)

The average total cost per mile decreased from the first phase for the  (Figure 3-10a). Phase 2 and 3 Diesel buses have a significantly lower total cost per mile than the Phase 1 Diesel buses. While the Phase 3 buses have a lower total cost per mile than the Phase 2 Diesel buses, the difference is not statistically significant.

**Figure 3-10. Mean total cost per mile for a)Phase 1,2, and 3 diesel and b) Phase 2 and 3 CNG.**




4. Phase 2 CNG vs. Phase 3 CNG: F-value = 89.252 P-value = 0. 0001 (Highly significant difference)

The average total cost per mile decreased considerably for the CNG buses from Phase 2 to Phase 3 (Figure 3-10b). The third phase of the Safe School Bus Program produced total cost per mile numbers for the CNG buses comparable to those of the diesel buses. The last contrast was to test for a difference in mean total cost per mile between the Phase 3 Diesel and the Phase 3 CNG buses. No significant difference was found.

5. Phase 3 Diesel vs. Phase 3 CNG: F-value = 0.310 P-value = 0. 5803 (No significant difference)

Bus-to-bus variability of total cost per mile is of interest because it is an indication of how variable the results were for each Phase/Fuel type. High within-group variability would reduce the usefulness of future projections of associated costs. High within group variability also could be indicative of Phase/Fuel types that are more sensitive to driver and route differences.

### 3.1.6 Summary Data Results

- For fuel cost per mile there are four groups: Phase 2 Methanol, Phase 2 CNG, Phase 1 Diesel, and Phase 2 Diesel/ Phase 3 CNG/ Control Diesel/ Phase 3 Diesel.

- Each new phase of the Safe School Bus program brought significant improvements in the fuel cost per mile for CNG and diesel bus fleets.

- Within the Phase 3 CNG buses, the three districts had significantly different average fuel costs per mile.

### 3.2 Biweekly Data Analysis

The data collected for the Commission provided a great deal of information on bus operation at a very detailed level. The biweekly data were analyzed to identify such things as variability of cost per mile from week to week, distribution of repair and maintenance costs, effect of CNG quality on mileage, driver differences on the same bus, and bus differences with the same driver.

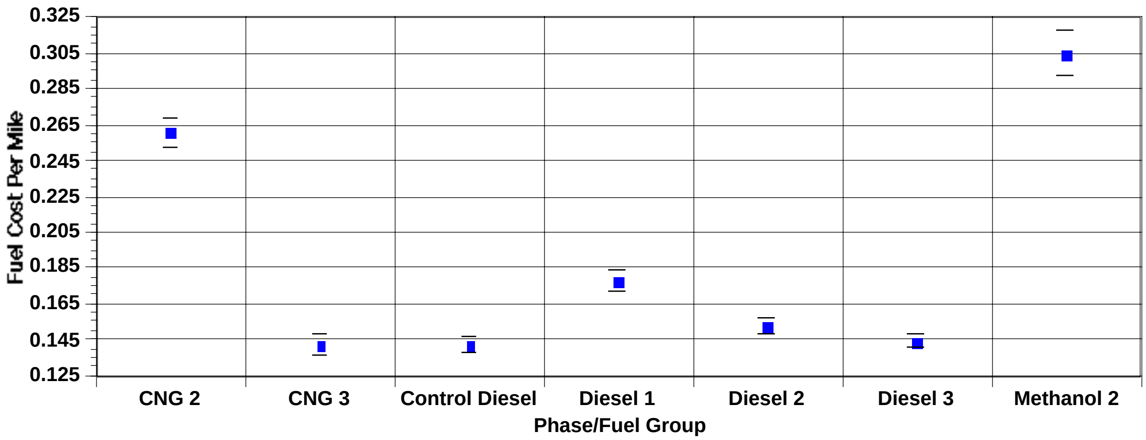
### 3.2.1 In-Use Cost Per Mile

The biweekly fuel cost per mile data were used to calculate the 95% confidence intervals for the mean fuel cost per mile of each bus type (Table 3-18 and Figure 3-11). The confidence intervals include the week to week variability in fuel cost per mile.

**Table 3-18. Fuel cost per mile mean and 95% confidence limits.**

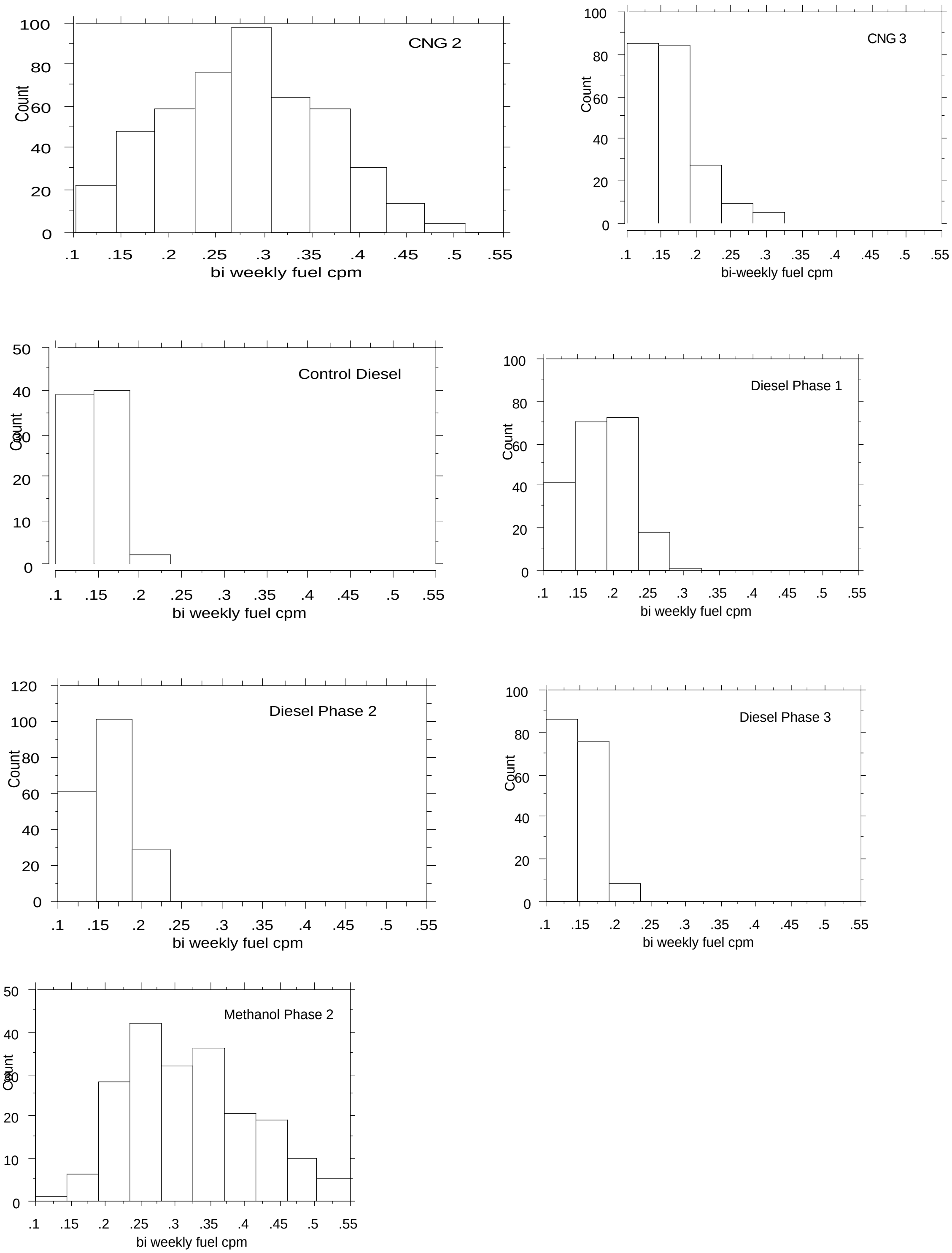
| Phase/Fuel Type | Mean Fuel Cost Per Mile | 95% Upper Confidence Limit | 95% Lower Confidence Limit |
|---|---|---|---|
| Phase 2 CNG | $0.260 | $0..268 | $0.252 |
| Phase 2 Methanol | $0.304 | $0.316 | $0.292 |
| Control Diesel | $0.142 | $0.146 | $0.138 |
| Phase 2 Diesel | $0.152 | $0.156 | $0.148 |
| Phase 1 Diesel | $0.177 | $0.183 | $0.171 |
| Phase 3 CNG | $0.142 | $0.148 | $0.136 |
| Phase 3 Diesel | $0.144 | $0.148 | $0.140 |

**Figure 3-11. Fuel cost per mile mean and 95% confidence limits.**




Fuel cost per mile was not consistent among buses of the same type, and there was no pattern of variability from group to group. The confidence limits are not exact for data that are not normally distributed, and the raw date provide valuable information on the range of fuel cost per mile results obtained in the operating conditions covered in this study. Histograms of biweekly fuel cost per mile are presented for each bus type (Figure 3-12 a-g).

**Figure 3-12. Histograms of biweekly fuel cost per mile data for a) CNG Phase 2, b) CNG Phase 3, c) diesel control, d) diesel Phase 1, e) diesel Phase 2, f) diesel Phase 3, and g) methanol Phase 2.**

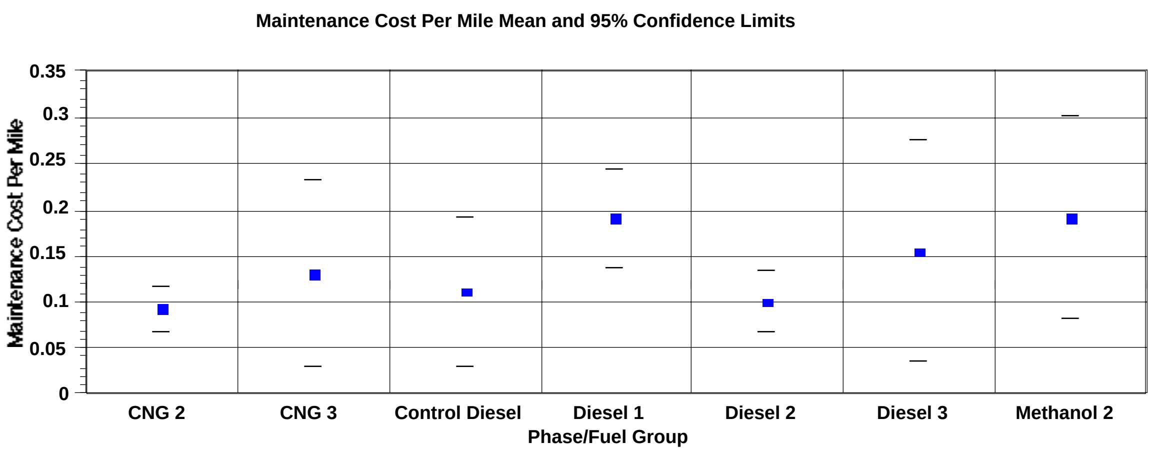


The bus-to-bus variability of maintenance cost per mile was used to calculate the 95% confidence intervals for the mean maintenance cost per mile of each bus type (Table 3-19 and Figure 3-13). This was done because of the irregular nature of the maintenance data, with many of the biweekly time periods having no work performed on one or more of the study buses.

**Table 3-19. Maintenance cost per mile mean and 95% confidence limits.**

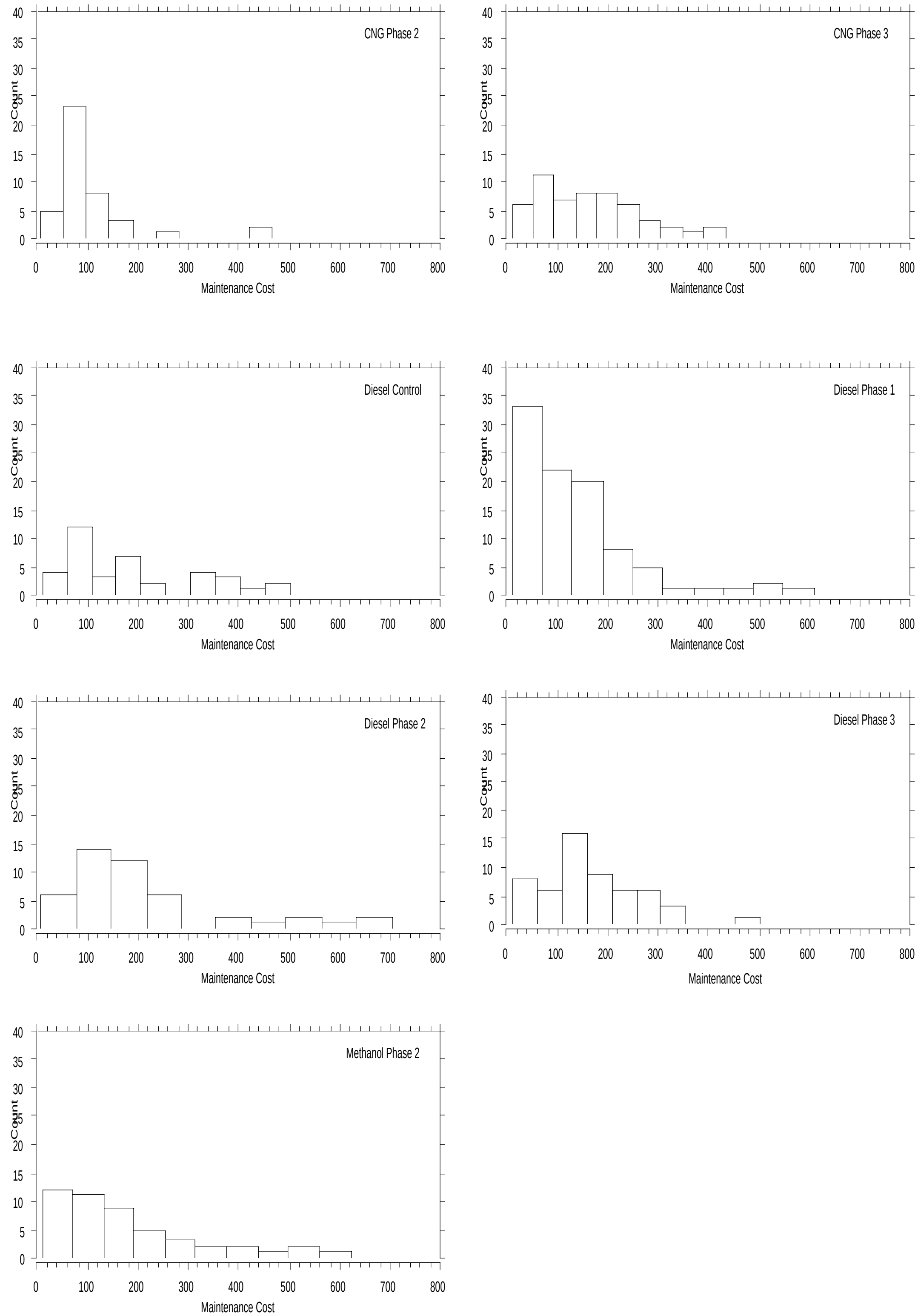
| Phase/Fuel Type | Mean Maintenance Cost Per Mile | 95% Upper Confidence Limit | 95% Lower Confidence Limit |
|---|---|---|---|
| Phase 2 CNG | $0.092 | $0.117 | $0.067 |
| Phase 2 Methanol | $0.191 | $0.302 | $0.080 |
| Control Diesel | $0.111 | $0.192 | $0.030 |
| Phase 2 Diesel | $0.100 | $0.132 | $0.068 |
| Phase 1 Diesel | $0.190 | $0.245 | $0.135 |
| Phase 3 CNG | $0.131 | $0.232 | $0.030 |
| Phase 3 Diesel | $0.155 | $0.275 | $0.035 |

**Figure 3-13. Maintenance cost per mile mean and 95% confidence limits .**




Histograms of maintenance cost are presented for each bus type (Figure 3-14 a-g). The distribution of the actual costs is presented. Although overall maintenance cost per mile was consistent among groups, some differences in the cost breakdown of the maintenance items exist. The CNG Phase 2 buses did not have as many of the higher-cost maintenance items as the other bus types. In addition, the diesel Phase 1 buses had a higher proportion of low-cost maintenance items than the other diesel buses. This indicates that the Phase 2 diesel buses with a lower cost per mile had more miles driven between maintenance events.

**Figure 3-14. Histograms of maintenance cost per item for a) CNG Phase 2, b) CNG Phase 3, c) diesel control, d) diesel Phase 1, e) diesel Phase 2, f) diesel Phase 3, and g) methanol Phase 2.**

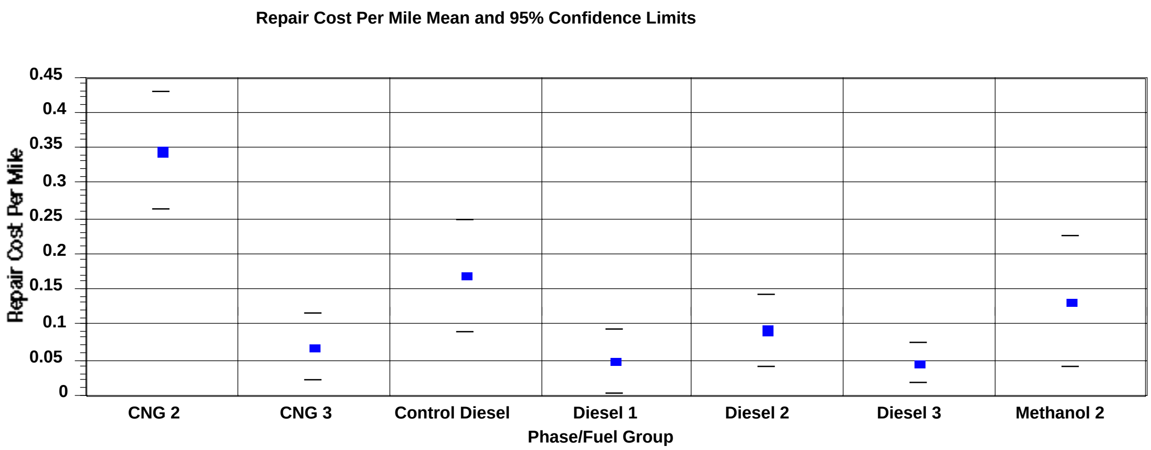


The bus-to-bus variability of the repair cost per mile data was used to calculate the 95% confidence intervals for the mean repair cost per mile of each bus type (Table 3-20 and Figure 3-15). This was done because of the irregular nature of the maintenance data; many of the biweekly time periods had no work performed on one or more of the study buses.

**Table 3-20. Repair cost per mile mean and 95% confidence limits.**

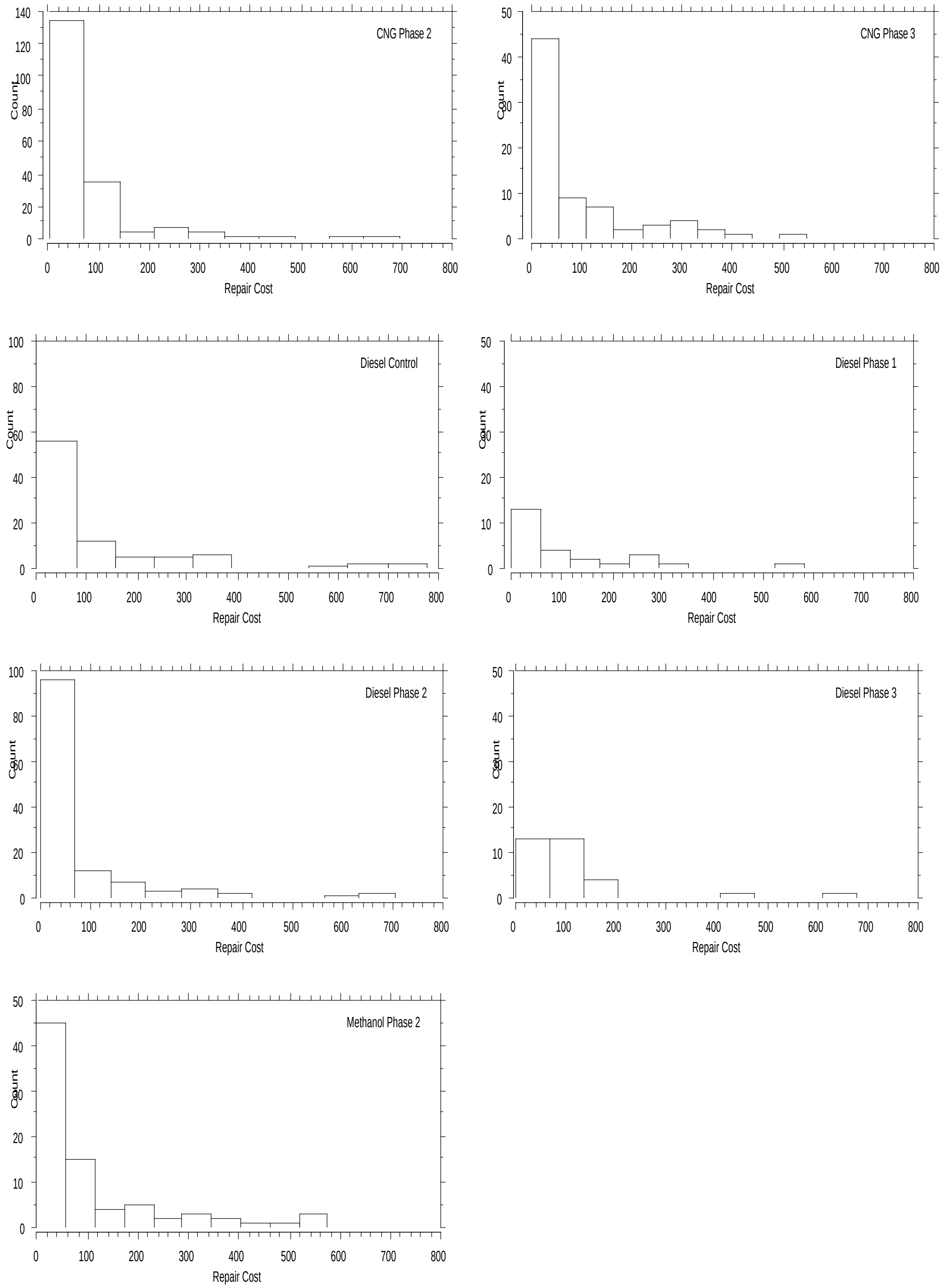
| Phase/Fuel Type | Mean Repair Cost Per Mile | 95% Upper Confidence Limit | 95% Lower Confidence Limit |
|---|---|---|---|
| Phase 2 CNG | $0.345 | $0.428 | $0.262 |
| Phase 2 Methanol | $0.132 | $0.224 | $0.040 |
| Control Diesel | $0.168 | $0.246 | $0.090 |
| Phase 2 Diesel | $0.091 | $0.142 | $0.040 |
| Phase 1 Diesel | $0.046 | $0.092 | $0.0001 |
| Phase 3 CNG | $0.068 | $0.116 | $0.020 |
| Phase 3 Diesel | $0.044 | $0.074 | $0.014 |

**Figure 3-15. Repair cost per mile mean and 95% confidence limits .**




Histograms of repair cost are presented for each bus type (Figure 3-16 a-g). The distribution of the actual costs is presented. The repair data on a cost-per-mile basis showed significant differences between bus types, with the CNG Phase 2 buses having significantly higher repair costs per mile than the other types. From the histograms of the cost of repair events it is evident that the CNG Phase 2 buses and the diesel control buses have somewhat higher-cost repair events. In addition, the CNG Phase 2 buses have more frequent repairs.

**Figure 3-16. Histograms of repair cost per item for a) CNG Phase 2, b) CNG Phase 3, c) diesel control, d) diesel Phase 1, e) diesel Phase 2, f) diesel Phase 3, and g) methanol Phase 2.**




## 3.2.2 Billing Factor Analysis

Results from Section 3.1 indicated that there were significant differences in miles per therm between the three school districts. Billing factor data were collected from the districts and from Pacific Gas & Electric for the gas used in the three districts during the time of the study. The billing factor is a measure of the heating value of the CNG and was a possible explanatory variable for the MPT differences observed in Section 3.1.

The Miles Per Therm and Billing Factor data were averaged over corresponding time periods and are presented in Table 3-21.

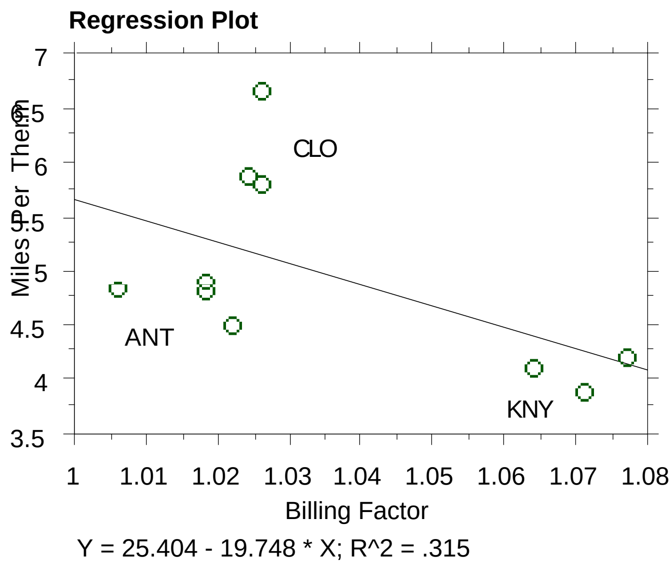
**Table 3-21 Average billing factor and miles per therm for Phase 3 CNG study buses.**

| District (Time Period) | Billing Factor | Miles Per Therm |
|---|---|---|
| KNY (January, 1997) | 1.064 | 4.116 |
| KNY (February, 1997) | 1.071 | 3.890 |
| KNY (March, 1997) | 1.077 | 4.214 |
| CLO (1/16/97 - 2/18/97) | 1.026 | 5.818 |
| CLO (2/18/97 - 3/19/97) | 1.024 | 5.892 |
| CLO (3/19/97 - 4/18/97) | 1.026 | 6.650 |
| ANT (January, 1997) | 1.018 | 4.803 |
| ANT (February, 1997) | 1.022 | 4.490 |
| ANT (March, 1997) | 1.018 | 4.907 |
| ANT (April, 1997) | 1.006 | 4.827 |

A regression was run to fit a line to the data with billing factor as the independent (x) variable and miles per therm as the dependent (y) variable. The regression (Figure 3-17) was significant at the 10% level (.10) with a p-value of 0.0913 and an R-Square of .315. This means that billing factor explains about 31.5% of the variability in miles per therm. This level of significance indicates that there is probably an effect of gas quality on the fuel economy of the Phase 3 CNG buses, but there is insufficient data to make a strong conclusion. Typically, a significance level of .10 is used in screening for effects for future study and is appropriate in this case.

A designed study with buses fueled using three to five equally spaced grades of CNG would be the best method for identifying the existence and magnitude of the fuel quality effect.

**Figure 3-17. Regression plot of miles per therm vs. billing factor for Phase 3 CNG buses.**




### 3.2.3 Within-Driver Bus Differences

The biweekly data were checked for drivers who had more than one bus and buses that had more than one driver during the study period. No significant differences in fuel economy were found.

## 3.3 Emissions Analysis

CE-CERT has conducted an analysis of the available emissions data for the alternative fuel buses. This analysis has been focused on two main areas: (1) identification of emissions mean and variance within Phase/Fuel Type groupings, and (2) analysis of emissions for individual buses run on more than one driving cycle.

### 3.3.1 Phase/Fuel analysis

Emissions were compared between fuel types where applicable, but not all emissions were measured on all bus types. Results are presented for all fuel types with data existing on at least two tests run on the Central Business District (CBD) test cycle. The CBD cycle had the highest number of test runs available for analysis. For this analysis, results are averaged across buses within fuel types, and the standard deviation is an overall error term including bus-to-bus variability as well as test run variability.

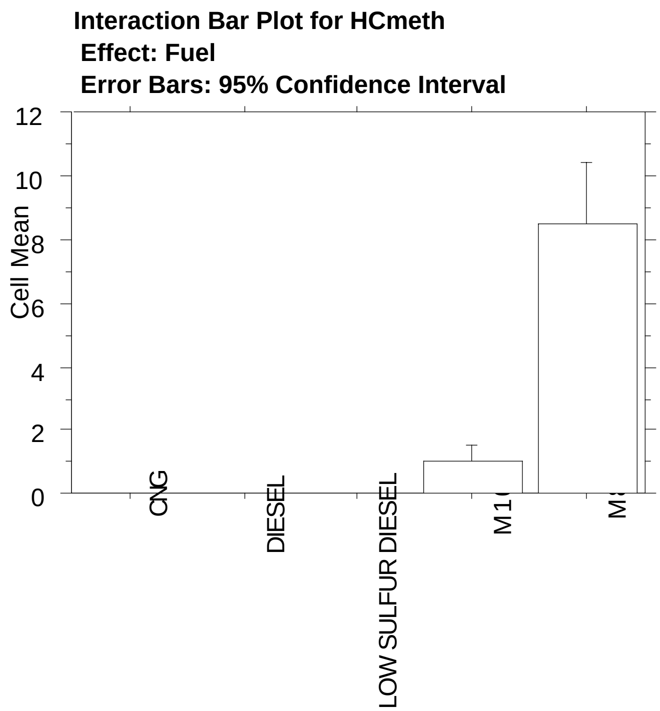
Significant differences ($p<.0001$) were found between mean emissions of hydrocarbon methane for the M100 and the M85 school buses (Table 3-22 and Figure 3-18). The M85 group had 8 times the hydrocarbon methane emissions of the M100 group.

**Table 3-22. Mean hydrocarbon methane emissions.**

**Means Table for HCmeth**
**Effect: Fuel**

| | Count | Mean | Std. Dev. | Std. Err. |
|---|---|---|---|---|
| CNG | 0 | • | • | • |
| DIESEL | 0 | • | • | • |
| LOW SULFUR DIESEL | 0 | • | • | • |
| M100 | 7 | 1.040 | .453 | .171 |
| M85 | 7 | 8.495 | 2.066 | .781 |

**Figure 3-18. Mean HC methane emissions with 95% confidence limit.**



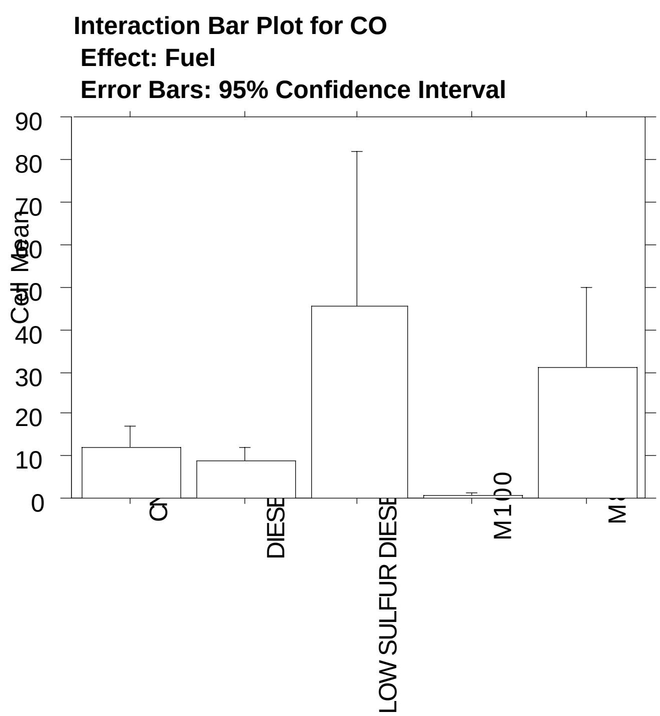

Significant differences ($p<.0001$) were found in carbon monoxide (CO) emission rates between fuel types (Table 3-23 and Figure 3-19). The low sulfur diesel and the M85 groups had much higher CO levels than the others. Much higher variability also was observed in the low sulfur diesel and M85 test results.

**Table 3-23. Mean carbon monoxide (CO) emissions.**

**Means Table for CO**
**Effect: Fuel**

| | Count | Mean | Std. Dev. | Std. Err. |
|---|---|---|---|---|
| CNG | 13 | 11.921 | 7.829 | 2.171 |
| DIESEL | 10 | 8.876 | 4.602 | 1.455 |
| LOW SULFUR DIESEL | 7 | 45.813 | 38.737 | 14.641 |
| M100 | 7 | .650 | .967 | .365 |
| M85 | 7 | 30.961 | 20.606 | 7.788 |

**Figure 3-19. Mean carbon monoxide emissions with 95% confidence interval.**



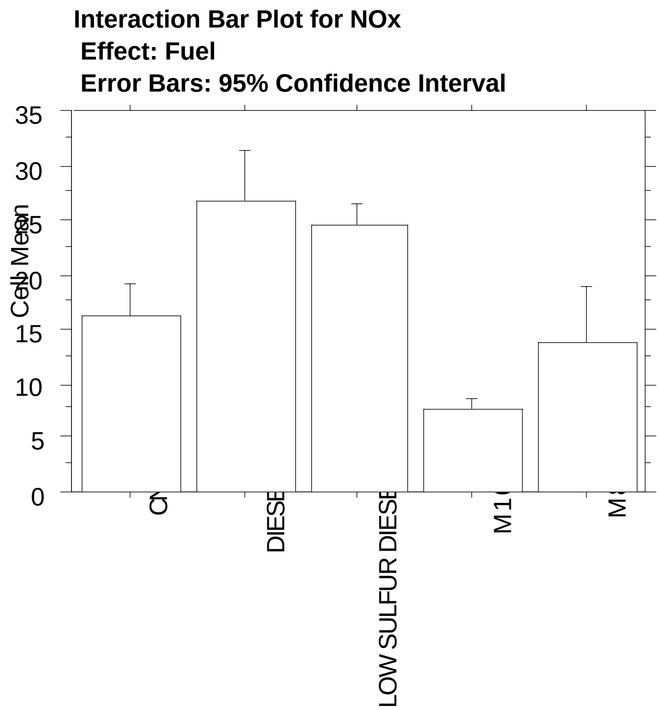

Significant differences (p<.0001) were observed between emission rates for oxides of nitrogen (NOx) (Table 3-24 and Figure 3-20). The diesel and low sulfur diesel groups had much higher emission rates than the others.

**Table 3-24. Mean NOx emissions.**

**Means Table for NOx**
**Effect: Fuel**

| | Count | Mean | Std. Dev. | Std. Err. |
|---|---|---|---|---|
| CNG | 13 | 16.337 | 4.656 | 1.291 |
| DIESEL | 10 | 26.660 | 6.480 | 2.049 |
| LOW SULFUR DIESEL | 7 | 24.557 | 2.102 | .795 |
| M100 | 7 | 7.561 | 1.013 | .383 |
| M85 | 7 | 13.923 | 5.563 | 2.103 |

**Figure 3-20. Mean NOx emissions with 95% confidence interval.**




## 3.4 Antelope Valley Phase/Fuel Type by Driver/Route Interaction Study

Section 2.4 describes a focused study that was conducted to determine the effect of route on bus performance. The data from this study were analyzed using a two way ANOVA with 2 replicates. The main effects to be tested are for driver/route differences and bus type differences. The Driver/Route by Bus Type interaction was also tested for significance. Summary data from this study is provided in Table 3-25.

**Table 3-25. Antelope Valley study data.**

| Driver | Bus | Start Odometer | End Odometer | Route Miles | Fuel (gal./ therms) | mpg or mpt | Fuel Price | Fuel Cost | Fuel cpm |
|---|---|---|---|---|---|---|---|---|---|
| 1 | ANT34-92 | 113049 | 113131 | 17.700 | 82.000 | 4.633 | .89 | 15.753 | .192 |
| 3 | ANT34-92 | 112959 | 113049 | 18.800 | 90.000 | 4.787 | .89 | 16.732 | .186 |
| 2 | ANT34-92 | 112896 | 112959 | 13.300 | 63.000 | 4.737 | .89 | 11.837 | .188 |
| 1 | ANT34-92 | 112812 | 112896 | 15.700 | 84.000 | 5.350 | .89 | 13.973 | .166 |
| 3 | ANT34-92 | 113196 | 113285 | 18.900 | 89.000 | 4.709 | .89 | 16.821 | .189 |
| 2 | ANT34-92 | 112661 | 112723 | 12.800 | 62.000 | 4.844 | .89 | 11.392 | .184 |
| 1 | ANT7-92 | 40431 | 40509 | 32.234 | 78.000 | 2.420 | .66 | 21.274 | .273 |
| 3 | ANT7-92 | 40659 | 40744 | 39.000 | 85.000 | 2.156 | .66 | 26.020 | .306 |
| 2 | ANT7-92 | 40744 | 40801 | 26.037 | 57.000 | 2.189 | .66 | 17.184 | .301 |
| 1 | ANT7-92 | 40237 | 40315 | 27.625 | 78.000 | 2.824 | .66 | 18.233 | .234 |
| 3 | ANT7-92 | 40573 | 40659 | 39.357 | 86.000 | 2.185 | .66 | 25.976 | .302 |
| 2 | ANT7-92 | 40509 | 40573 | 30.218 | 64.000 | 2.118 | .66 | 19.944 | .312 |
| 1 | ANT2-96 | 31827 | 31910 | 19.759 | 83.000 | 4.201 | .66 | 13.041 | .157 |
| 3 | ANT2-96 | 31977 | 32067 | 22.571 | 90.000 | 3.987 | .66 | 14.897 | .166 |
| 2 | ANT2-96 | 31910 | 31977 | 18.106 | 67.000 | 3.700 | .66 | 11.950 | .178 |
| 1 | ANT2-96 | 31586 | 31668 | 18.579 | 82.000 | 4.414 | .66 | 12.262 | .150 |
| 3 | ANT2-96 | 31737 | 31827 | 22.581 | 90.000 | 3.986 | .66 | 14.903 | .166 |
| 2 | ANT2-96 | 31669 | 31737 | 17.303 | 68.000 | 3.930 | .66 | 11.420 | .168 |

In most cases, bus performance was consistent from driver to driver. This made it possible to analyze differences in bus types (Table 3-26). These results correlated with the broader findings that the Phase 3 CNG and Phase 3 diesel buses have similar overall operating costs per mile, and that Phase 2 CNG is considerably more expensive per mile than the Phase 3 vehicles (Table 3-27).

**Table 3-26. Driver effect on fuel cost per mile.**

**Means Table**
**Effect: Driver/Route**
**Dependent: Fuel cpm ($)**

| | Count | Mean | Std. Dev. | Std. Error |
|---|---|---|---|---|
| 1 | 6 | .195 | .049 | .020 |
| 2 | 6 | .219 | .067 | .027 |
| 3 | 6 | .222 | .066 | .027 |

## Table 3-27. Mean fuel cost per mile by bus.

| | Count | Mean | Std. Dev. | Std. Error |
|---|---|---|---|---|
| PHASE 2 CNG | 6 | .288 | .030 | .012 |
| PHASE 3 CNG | 6 | .164 | .010 | .004 |
| PHASE 3 DIESEL | 6 | .184 | .009 | .004 |

**Table 3-33**. Mean Fuel CPM by bus.

# 4. Conclusions and Recommendations

## 4.1 Conclusions

Major findings of this project are summarized as follows:

Fuel Cost Per Mile

- Diesel Phase 2, diesel Phase 3, and CNG Phase 3 buses were found to have no significant difference in fuel cost per mile from pre-1977 control diesel buses in use during the study period.
- Significantly different miles per therm were found between the three school districts within the Phase 3 CNG buses. This may be due to fuel quality.
- In the Antelope Valley small scale study, the Phase 3 CNG bus had significantly lower fuel cost per mile than the Phase 3 diesel bus.
- Significant improvement in fuel cost per mile was found in Phase 2 and Phase 3 diesel buses compared with Phase 1 diesel buses.
- Phase 3 CNG buses showed significant improvement over Phase 2 CNG buses in fuel cost per mile.

Maintenance Cost Per Mile

- High bus-to-bus variability was observed in maintenance cost per mile.
- No significant difference in maintenance cost per mile was found between bus types.

Repair Cost Per Mile

- Phase 3 CNG, Phase 1 diesel and Phase 3 diesel buses had significantly lower repair cost per mile than the control diesel buses.
- No significant difference in repair cost per mile was found between Phase 1 diesel, Phase 2 diesel, Phase 3 diesel, and Phase 3 CNG buses.

Total Cost Per Mile

- Phase 2 CNG and Phase 2 methanol were significantly higher in total cost per mile than the control diesel, Phase 1,2,and 3 diesel, and Phase 3 CNG bus group.

Total Cost Per Mile Excluding Maintenance

- Phase 3 CNG and Phase 3 diesel had significantly lower cost per mile than the control diesel buses.

- Phase 2 CNG had significantly higher cost per mile than all other bus types.

- Phase 2 methanol had significantly higher total cost per mile than all but the Phase 2 CNG bus type.

Billing Factor Analysis

- A weak correlation between billing factor and miles per therm was found in the CNG buses
.
- Results were inconclusive given the data currently on hand.

In Use Analysis

- No significant difference in miles per therm was found between two CNG Phase 2 buses when driven by the same driver.

- No significant differences were found in miles per therm on a CNG Phase 2 bus driven by two different drivers over different routes.

### 4.2 Recommendations

Based on the results of this project, CE-CERT recommends the following actions:

1. **Dynamometer emissions testing.** Although the California Energy Commission's primary concern is energy efficiency, diversity, and security, but a major driving force behind alternative fuels is the impact on emissions. Although a small amount of dynamometer testing has been performed on alternative-fuel school buses, more data are required to quantify the emissions impacts. This information, coupled with data analysis on operating costs, will contribute to a cost-effectiveness analysis that takes into account all of the systemic impacts and societal costs of vehicle operation.

2. **Development of a school bus testing cycle.** Route characteristics have been found to be an extremely influential variable affecting school bus energy consumption. Although standard dynamometer testing cycles exist to represent a number of typical driving patterns for cars, trucks, and buses (such as the Federal Test Procedure, the Central Business District cycle, and Los Angeles and New York cycles), none accurately represents urban or rural school bus cycles. The ability to accurately portray school bus operational requirements would improve the ability of manufacturers, school districts, the Energy Commission, and other interested parties to (1) develop more energy-efficient vehicles and (2) make appropriate acquisition decisions. Development of such a model

would require more data collection, reduction, and analysis, as well as experimental work on a medium/heavy-duty chassis dynamometer.

3. **Modeling of school bus energy consumption.** CE-CERT's Transportation Systems Research Group is completing an Integrated Transportation/Emissions Model (ITEM), a deterministic model that can be used to predict emissions from a single vehicle or a large vehicle population at the micro or macro scales. Fuel consumption is modeled within ITEM. A more thorough analysis of existing data, coupled with additional detailed data collection, would enable CE-CERT to create a model that could predict school bus energy consumption on a route-by-route basis.

4. **More detailed data collection.** As described in this report, most data collection was accomplished using comparatively low-resolution "bin" techniques. Some data, however, were collected on a second-by-second basis, which provided a much clearer picture of vehicle operations. It is recommended that highly time-resolved data be collected and analyzed for future projects of this nature.

## Appendix 1
*Data File Descriptions*

**BASE DATA (BASEDATA.DBF)**

| FIELD NAME | DESCRIPTION | SAMPLE ENTRY |
|---|---|---|
| UNIT_ID | DAS Identification Number | 395 |
| FIRST_USE | Beginning Date & Time | 19970101275544 |
| LAST_USE | Ending Date & Time | 19970101282555 |
| TRIP_DUR | Time of recording period | 851 |
| FIRST_ODOM | Beginning Odometer | 41286.2 |
| LAST_ODOM | Ending Odometer | 212889.3 |
| TRIP_DIST | Distance Traveled | 13.1 |
| FIRST_FUEL | Number of gallons | 1121 |
| LAST_FUEL | Number of gallons | 2222 |
| TRIP_FUEL | Total gallons used | 1.11 |
| TRIP_MPG | Average MPG for the trip | 1.111 |
| ENG_IDLE | Time engine was idling | 616 |
| FILL_COUNT | No. of Tank Fill Operations | 1 |
| EMR_COUNT | No. of times reserve 6th tank was used | 0 |

**Figure DC-1**: Contains one record for each vehicle for each recording period. This data file records fuel consumption data from buses with DDEC electronic controls, pre-1977 control and Phase 2 methanol buses.

**(EMOTHER.DBF)**

| FIELD NAME | DESCRIPTION | SAMPLE ENTRY |
|---|---|---|
| owonum | work order number | 28731 |
| otype | code for type of maintenance performed | 10 |
| odesc | description of maintenance | JUMP BUS |
| oqty | number of hours | 0.25 |
| ocost | cost per hour for vehicle maintenance | 15.56 |
| odistname | school district | Antelope Valley STA |
| ofueltype | fuel type | DSL |
| oecode | Bus Identification Number | ANT--0022 |
| owdate | date of work order | 01/29/97 |
| ofinished | indicates if work order was completed | TRUE |
| ouploaded | | FALSE |

**Figure DC-2**: Contains work order data that covers cost and types of maintenance performed on vehicles other than parts.

## DRIVER LOG DATA (EMDAILY.DBF)

| FIELD NAME | DESCRIPTION | SAMPLE ENTRY |
|---|---|---|
| SCH_DIST | School District name | Antelope Valley ST |
| WEEKOF | Date week begins | 1/26/97 |
| ENTRYDATE | Date that bus was used/data written | 1/29/97 |
| DRIVER | Name of bus drver | Jane Doe |
| BUS_NO | Number to identify bus & district | ANT-0000 |
| FUELTYPE | Type of fuel | M100 |
| CONTROLBUS | Indicates a pre_77 control bus (Y/N) | N |
| ODOMETER | Current odometer reading | 23300 |
| PREV_ODOM | Previous odometer reading | 23000 |
| OIL_QTY | Number of quarts of oil added | 10 |
| FUEL_QTY | Number of gallons o fuel added | 100 |
| FUEL_THERM | Therms added fo CNG BUS | 26.85 |
| FUEL COST | Current unit cost for fuel | 2.15 |
| CNG_BEFPSI | PSI on CNG bus before fueling | 800 |
| CNG_BEFTMP | Temp reading on CNG bus before fueling(F) | 87.5 |
| CNG_AFTPSI | PSI on CNG bus fter fueling | 2800 |
| CNG_AFTTMP | Temp reading on CNG bus after fueling(F) | 79 |
| OIL_COST | Cost of one quart of oil | 5.25 |
| DOWNDAY | Indicates bus out of service (Y/N) | N |
| ROUTES | Total number of routes today | 10 |
| TRIPS | Total field trips today | 2 |
| STOPS | Total passenger stops today | 120 |

**Figure DC-3**: (ASIM) Driver Log data. This file contains the information taken from the driver's daily log. It gives the manually entered data for mileage, fuel consumption, and route information.

## (EMEQUIP.DBF)

| FIELD NAME | DESCRIPTION | SAMPLE ENTRY |
|---|---|---|
| ecode | Bus identification number | ANT--0000 |
| edesc | description of bus | 78 CARP 6V92 DDC |
| edept | phase | 2 |
| eassign | driver assigned to bus | JOHN DOE |
| ecntrcurr | odmeter reading | 50640 |
| ecntrdate | date of odoeter reading | 02/11/97 |
| elastfuel | | 50407 |
| elfuldate | | 02/05/97 |
| evin | vehicle identification number | 1C9CAH585NT493424 |
| ewght | weight of vehicle | |
| erenew | CHP renewal date | 04/04/97 |
| elic | vehicle license number | E372730 |
| etype | | 1 |
| ebegmile | | 44508 |
| elastyrml | | 19364 |
| eactive | | TRUE |
| eexpptd | | 12919 |
| eexpytd | | 4049.88 |
| eexptd | | 13146.61 |
| eexplast | | 14045.72 |
| eserv1 | | S |
| emile1 | | 48188 |
| efreq1 | | 0 |
| edays1 | | 0 |
| edate1 | | 12/02/96 |
| eserv2 | | U |
| emile2 | | 47240 |
| efreq2 | | 0 |
| edays2 | | 0 |
| edate2 | | 10/25/96 |
| eserv3 | | RC |
| emile3 | | 47964 |
| efreq3 | | 0 |
| edays3 | | 0 |
| edate3 | | 11/26/96 |
| eserv4 | | RC-WR |
| emile4 | | 0 |
| efreq4 | | 0 |
| edays4 | | 0 |
| edate4 | | - - |
| eserv5 | | U-WR |
| emile5 | | 47647 |
| efreq5 | | 0 |
| edays5 | | 0 |
| edate5 | | 12/06/96 |
| eserv6 | | |
| emile6 | | 0 |
| efreq6 | | 0 |
| edays6 | | 0 |
| edate6 | | - - |
| efueltype | type of fuel used by bus | M100 |
| edistname | school district | Antelope Valley STA |
| elocation | location of school district | ANTELOPE VALLEY |
| econtrol | Indicates pre-77 contol bus (T=yes, F=NO) | FALSE |
| estmscode | | 25-92 |

**Figure DC-4**: General bus data.

### (EMWOHEAD.DBF)

| FIELD NAME | DESCRIPTION | SAMPLE ENTRY |
|---|---|---|
| wnum | work order number | 28731 |
| wecode | bus identification number | ANT--0000 |
| wtcode | indicates sort of maintenance call (RC-road call, U- | U |
| wmile | odometer reading at time of maintenance | 24013 |
| wdate | date of maintenance | 1/29/97 |
| wperform | | 3851 |
| wxtra1 | | 0 |
| wxtra2 | | 0 |
| wfinish | indcates if mantenace peforme | TRUE |
| wprinted | | FALSE |
| wdistname | school district | Antelope Valley STA |
| wfueltype | type of fuel used | DSL |
| wphase | phase | 2 |
| wuploaded | | FALSE |

**Figure DC-5**: Includes data from EMOTHER.DBF and EMPARTS.DBF and combines the two totals to show total overhead of work order.

### (TANKFILL.DBF)

| FIELD NAME | DESCRIPTION | SAMPLE ENTRY |
|---|---|---|
| UNIT_ID | DAS Idntification Number | 395 |
| FIRST_USE | Beginning Date & Time | 19970101264018 |
| LAST_USE | Ending Date & Time | 19970101184325 |
| FILL_BEGIN | Date & Time of Fill Begin | 19970101175240 |
| FILL_ODOM | Odo reading during refueling | 244.5 |
| TMPLEV_BEG | Beginning Tank Temp or Level | 2141 |
| PRES_BEG | Beginning Tank Pressure | 856 |
| FILL_END | Date & Time of Fill End | 19970101181058 |
| TEMPLEV_END | Ening ank Temp or Level | 2324 |
| PRES_END | Eding Tank Pressure | 1886 |
| FILL_DIST | Distance since last refueling | 0.5 |

**Figure DC-6**: Contains one record for each CNG tank filling operation, detected by an algorithm (**see else**) and the fuel door switch, with a maximum of fifty records for each vehicle recording period.

### (EMPARTS.DBF)

| FIELD NAME | DESCRIPTION | SAMPLE ENTRY |
|---|---|---|
| wwonum | work order number | 28607 |
| wpart | prt number | 238209 |
| wdesc | description of part | 85/140 GEAR OIL PER QUART |
| wcatg | declares what sort of part is used | ENGI |
| wservtype | | S |
| wqty | number of parts or units of oil used | 4.5 |
| wsell | cost of part or ost per unit of oil | 1.06 |
| wdistname | school district | Antelope Valley STA |
| wfueltype | fuel type | DSL |
| wecode | Bus Identification Number | ANT--3592 |
| wwdate | Date of maintenance | 01/29/97 |
| wfinished | Indicates if maintenance was completed | TRUE |
| wuploaded | | FALSE |

**Figure DC-7**: Contains work order data on parts used in repairs, including quantity and cost.

**Note:** Fields without descriptions were not important to the study and not used in any of the analysis of calculations

**Appendix 2**

***California Energy Commission Bus Specification Form***

| Vehicle System | Diesel Phase 1 | Diesel Phase 2 | Methanol Phase 2 | CNG Phase 2 | Diesel Phase 3 | CNG Phase 3 |
|---|---|---|---|---|---|---|
| **General Bus Specifications** | | | | | | |
| Bus Number | | | | | | |
| Bus Manufacturer | Crown Coach | Thomas | Carpenter | Bluebird | Bluebird | Bluebird |
| Bus Model | 2R-38N-552 | 14055 SAT T Liner | 3908 | AARE3903 | TC 2000 | TCRE 3803 |
| Bus Length, In. | 463 | 475 | 476 | 479 | 479 | 471 |
| Bus Width & Height, In. | 125, 96 | 123, 96 | 134, 96 | 120, 96 | 120, 96 | 125,96 |
| Gross Vehicle Wt. Rating Total, lb. | 36,200 | 36,200 | 36,200 | 36,200 | 36,200 | 36,200 |
| Curb Weight Total, lb. | | 22,671 | 24,610 | 24,184 | | 24,233 |
| Passenger Seats | 78 | 78 | 78 | 78 | 78 | 78 |
| **Engine/Fuel System** | | | | | | |
| Fuel Type/Additives | Diesel/None | Diesel/None | Methanol/Lubrizol | CNG/None | Diesel/None | CNG/None |
| Engine Manufacturer | Detroit Diesel | Caterpillar | Detroit Diesel | Tecogen | Caterpillar | John Deere |
| Engine Model Number | 6V-92TA | 3116A | 6V-92TA | 7000T | 3126TA | Series 450 6081HFN |
| Year of Manufacture | | 1990 | 1992 | 1992 | 1996 | 1995 |
| Compression Ratio | 17/1 | 16.5/1 | 23/1 | 9.2/1 | 16/1 | 10/1 |
| Type of Ingnition Aid Used | None | None | Glow Plugs | Spark Plugs | None | Spark Plugs |
| Engine Cycle | 2 | 4 | 2 | 4 | 4 | 4 |
| Engine Type | V-6 | In-Line 6 | V-6 | V-8 | In-Line 6 | In-Line 6 |
| BHP Maximum and RPM | 253 bhp @1950 rpm | 249 bhp @ 2600rpm | 253 bhp @ 1950 rpm | 222 bhp @ 3600 rpm | 250 bhp @ 2200 rpm | 250 bhp @ 2200 rpm |
| Torque Maximum and RPM | 880 flb @ 1200 rpm | 650 flb @ 1560 rpm | 880 flb @ 1200 rpm | 425 flb @ 2200 rpm | 860 flb @ 1140 rpm | 800 flb @ 1350 rpm |
| Displacement (L) | 9.05 | 6.6 | 9.05 | 7 | 7.2 | 8.1 |
| Blower? (Yes/No) | Yes | No | Yes | No | No | No |
| Turbocharger? (Yes/No) | Yes | Yes | Yes | Yes | Yes | Yes |
| Aftercooling | Jacket Water | Air to Air | Jacket Water | Air to Air | Air to Air | Air to Air |
| Mechanical or Electronic Fuel Inj.? | Electric | Mechanical | Electric | Open Loop Carb | Electronic | Electronic |
| Number of Injectors | 6 | 6 | 6 | 1 | 6 | 8 |
| Direct Inj. or Fumigation? | Direct Injection | Direct Injection | Direct Injection | Stoichemetric | Direct Injection | Lean Burn |
| Number of Fuel Storage Tanks | 1 | 1 | 1 | 6 @ 3000 psi | 1 | 4 @ 3000 psi |
| Total Useful amount of Fuel Storage | 100 Gallons | 100 Gallons | 200 Gallons | 78 Therms | 100 Gallons | 74 Therms |
| **Transmission** | | | | | | |
| Manufacter and Model Number | Allison MT647 | Allison MT643 | Allison MT647 | Allison MT643 | MD3060 | MD3060 |
| Torque Conversion Ratio | | | | | | |
| Retarder? (Yes/No) | | No | No | No | No | No |
| **Safety Equipment** | | | | | | |
| Fire Detection (Yes/No) | | Yes | Yes | Yes | Yes | Yes |
| Fire Suppression (Yes/No) | | Yes | Yes | Yes | Yes | Yes |
| Vapor Detection (Yes/No) | | No | No | Yes | No | No |
| **Emmissions Equipment** | | | | | | |
| Catalytic Converter | None | Oxidizing | Oxidizing | Three-Way | Oxidizing | Three-Way |
| Diesel Particulate Trap (Yes/No) | | No | No | No | | No |

Figure xxx

**Appendix 3**
*QA/QC Log*

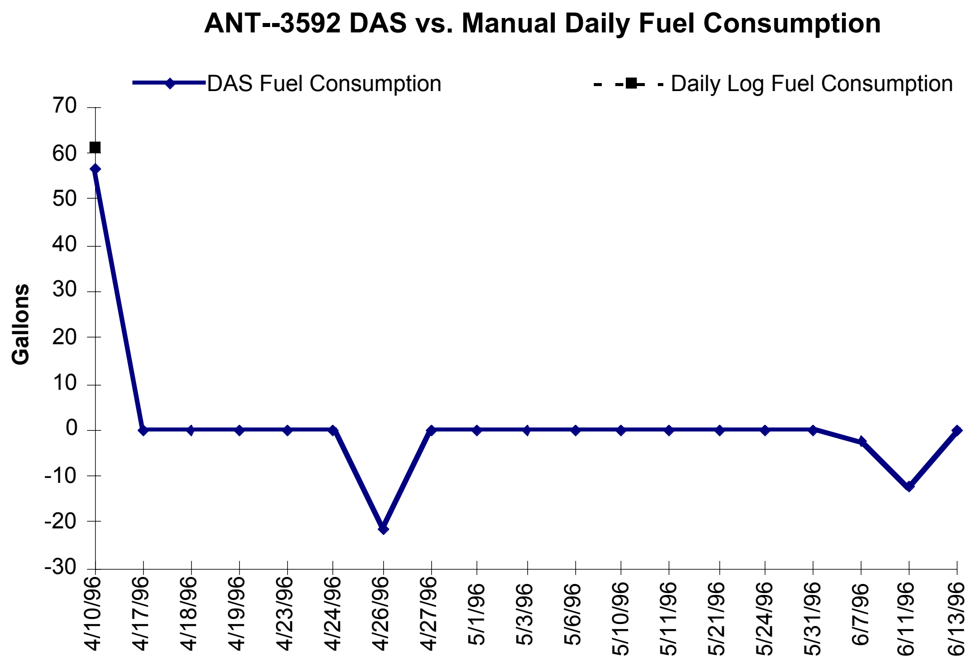



**Figure 1.** A graph of DAS fuel consumption vs. Manual fuel consumption for bus number 3592, a Diesel Phase 2 from the Antelope Valley School District. This graph shows that we have only received one point of Manual data (labeled Daily Log Fuel Consumption). It also shows that the DAS data CE-CERT has received has been either zero or a negative value for all but one point.

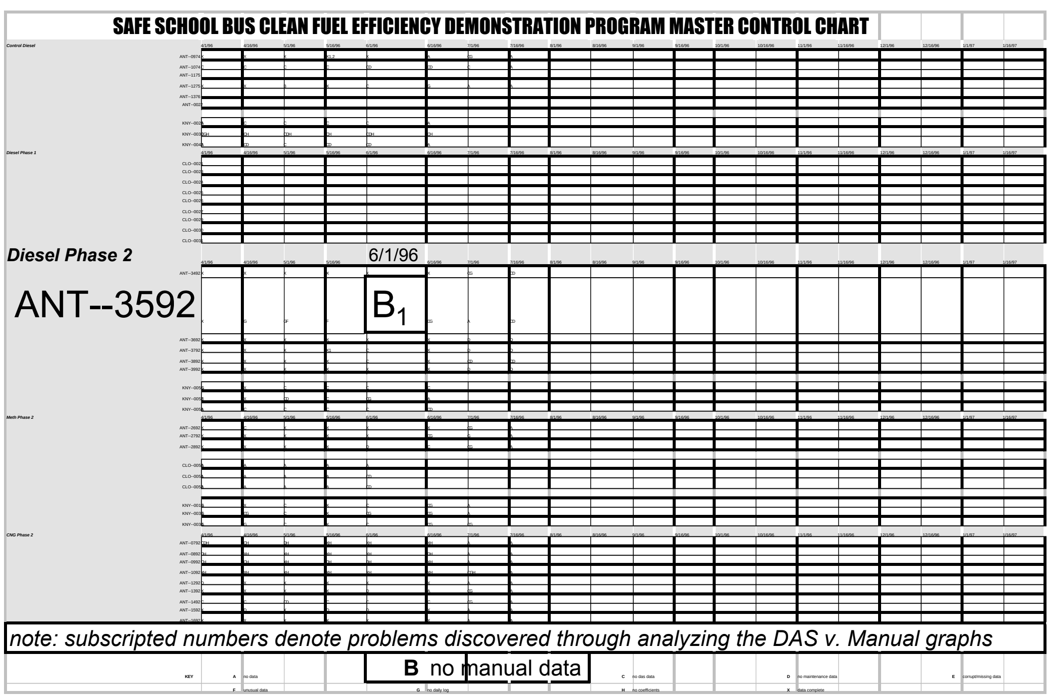


**Figure 2.** The Master Control Chart with school bus number 3592 highlighted. After the data is downloaded, the Visual FoxPro program sorts through the data for each bus during the two week collection period.

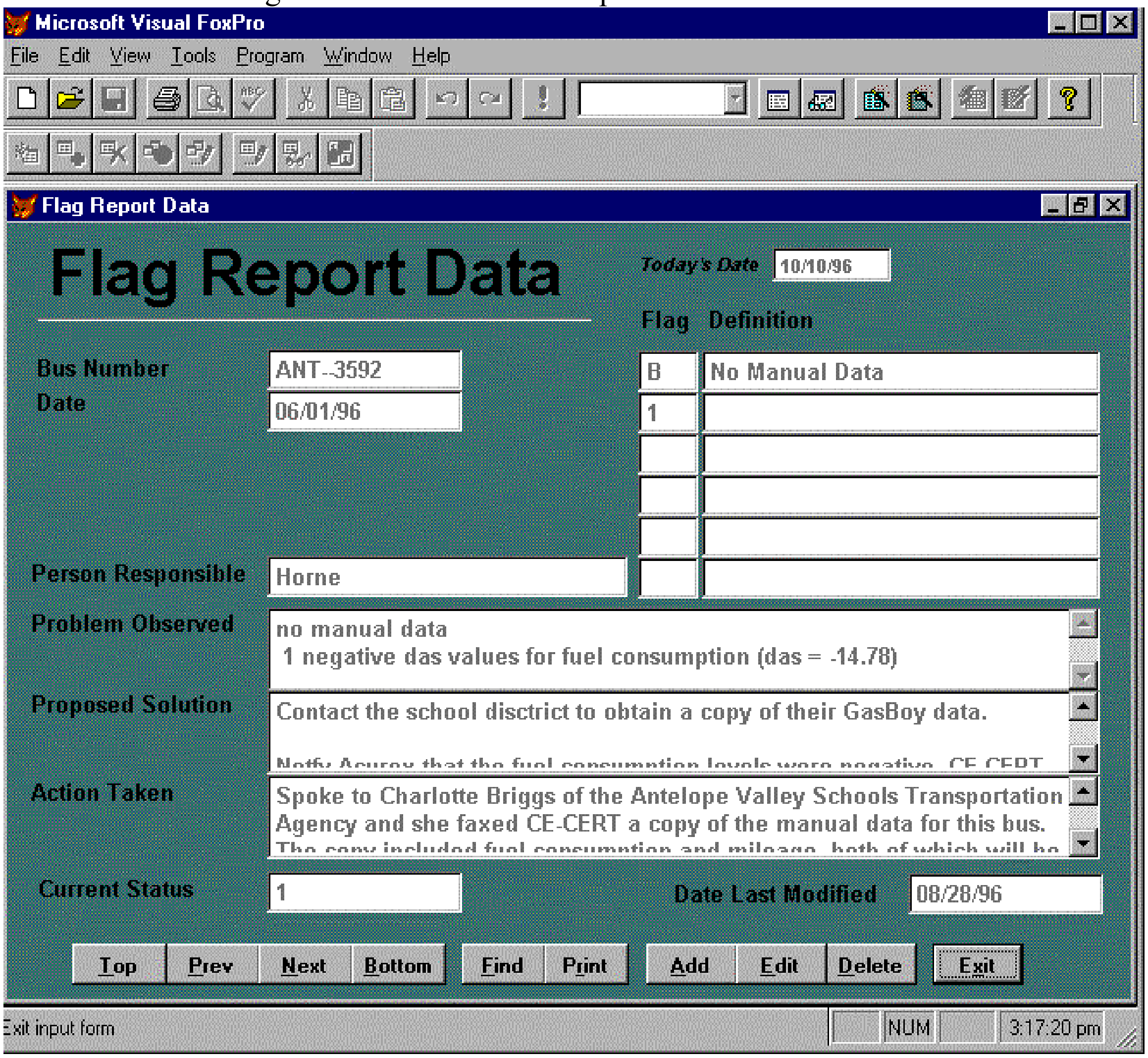



**Figure 3.** The user interface of the *QA/QC Log*. CE-CERT uses the interface after the graphs of DAS data vs. the Manual data have been examined, and after the data has been flagged by Visual FoxPro.

**BUS NO.** ANT--3592

| *recording period* | *flag code* | *problem description* | *proposed solution* | *member responsible* | *action taken* | *current status* |
|---|---|---|---|---|---|---|
| 6/1/96 | B | no manual data | Contact the school district to obtain a copy of their GasBoy data. | Horne | *Spoke to Charlotte Briggs of the Antelope Valley Schools Transportation Agency and she faxed CE-CERT a copy of the manual data for this bus. The copy included fuel consumption and mileage, both of which will be used to fill our missing data. | |
| | 1 | negative das values for fuel consumption (das= -14.78) | Notify the school district that the fuel consumption levels were negative. CE-CERT believes that this could be caused by the float becoming immobile. | | **Spoke to Jared Adams on 8/13/96 regarding the DAS and he stated that ARGO fixed it on 5/8/96. Terry examined the bus on 8/14/96 and discovered that a squirel had chewed away at the DAS wiring. CE-CERT will be notified when the DAS is repaired. | 1 |

**Figure 4.** The information input into the interface shown in Fig. 3 is then converted into a Microsoft Excel Sheet for quick access and usage between different computers.

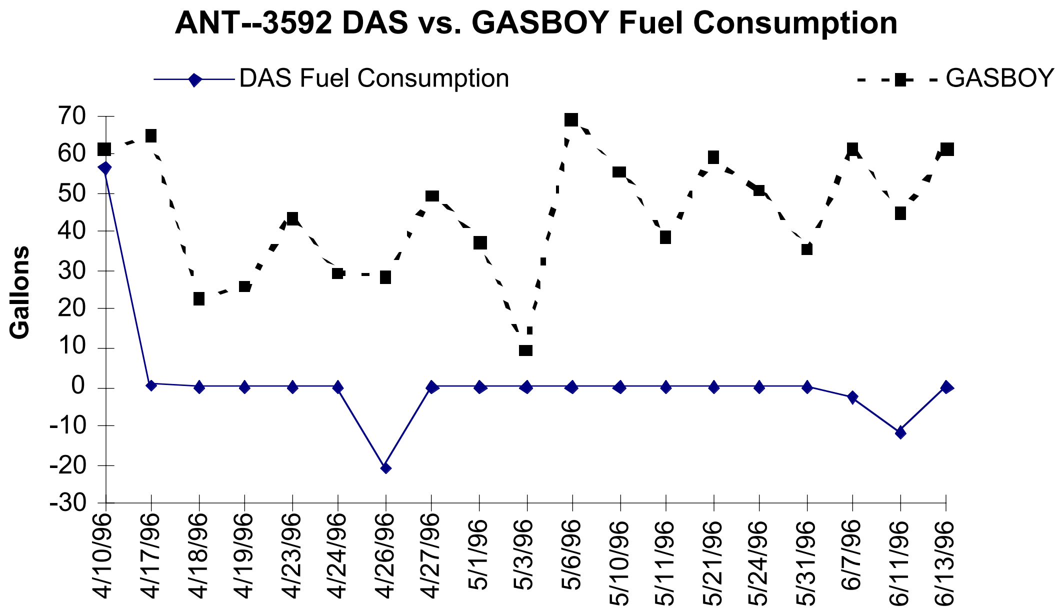



**Figure 5.** A graph of DAS fuel consumption vs. Manual Fuel consumption for bus number 3592 after CE-CERT utilized *QA/QC Log* process to identify and fix problems.

**Appendix 4**
***File Status***

| SAFE SCHOOL BUS CLEAN FUEL EFFICIENCY DEMONSTRATION PROGRAM MASTER | | | | | *FILE STATUS* | | | |
|---|---|---|---|---|---|---|---|---|
| *down load date:05-08-97* | | | | | | | | |
| | das number | basedata | emdaily | emequip | emwohead | tankfill | emparts | emother |
| ANT | | data | data | data | data | data | data | data |
| CLO | | data | data | data | data | data | data | data |
| KNY | | data | data | data | data | data | data | data |
| ***Control Diesel*** | | | | | | | | |
| ANT--0022 | 00428 | data | data | data | data | data | data | data |
| ANT--0974 | 00526 | data | data | data | data | data | not serviced | data |
| ANT--1074 | 00261 | data | data | data | data | data | data | data |
| ANT--1275 | 00320 | data | data | data | data | data | not serviced | data |
| ANT--0572 | 00448 | data | data | data | data | data | data | data |
| ANT--0672 | 00518 | data | data | data | data | data | data | data |
| KNY--0026 | 00425 | data | data | data | not serviced | data | not serviced | not serviced |
| KNY--0030 | 00507 | data | data | data | data | data | data | data |
| KNY--0042 | 00009 | data | data | data | not serviced | data | not serviced | not serviced |
| ***Diesel Phase 1*** | | | | | | | | |
| CLO--0021 | 01314 | data | data | data | data | | data | data |
| CLO--0023 | 01015 | data | data | data | not serviced | | not serviced | not serviced |
| CLO--0024 | 00734 | data | data | data | not serviced | | not serviced | not serviced |
| CLO--0025 | 00763 | data | data | data | data | | data | data |
| CLO--0026 | 00796 | data | data | data | not serviced | | not serviced | not serviced |
| CLO--0027 | 01216 | data | data | data | data | | data | data |
| CLO--0029 | 00281 | data | data | data | data | | data | data |
| CLO--0030 | 00871 | data | data | data | data | | data | data |
| CLO--0031 | 00948 | data | data | data | not serviced | | not serviced | not serviced |
| ***Diesel Phase 2*** | | | | | | | | |
| ANT--3492 | 00441 | data | data | data | data | data | data | data |
| ANT--3592 | 00476 | data | data | data | data | data | data | data |
| ANT--3692 | 00417 | data | data | data | not serviced | data | not serviced | not serviced |
| ANT--3792 | 00211 | data | data | data | data | 0 | data | data |
| ANT--3892 | 00022 | data | data | data | data | data | data | data |
| ANT--3992 | 00797 | data | data | data | data | 0 | data | data |
| KNY--0056 | 00099 | data | data | data | data | data | data | data |
| KNY--0057 | 00358 | data | data | data | not serviced | data | not serviced | not serviced |
| KNY--0058 | 00450 | data | data | data | not serviced | data | not serviced | not serviced |
| ***Diesel Phase 3*** | | | | | | | | |
| CLO--0053 | 01979 | data | data | data | not serviced | data | not serviced | not serviced |
| CLO--0054 | 01936 | data | data | data | data | data | data | data |
| CLO--0055 | 01810 | data | data | data | data | data | data | data |
| CLO--0067 | 00243 | data | data | data | data | data | not serviced | data |
| CLO--0068 | 01942 | data | data | data | data | data | data | data |
| KNY--0004 | 01927 | data | data | data | data | data | data | data |
| KNY--0012 | 02007 | data | data | data | not serviced | data | not serviced | not serviced |
| KNY--0024 | 02002 | data | data | data | data | data | data | data |
| KNY--0029 | 02012 | data | data | data | data | data | data | data |
| ***Meth Phase 2*** | | | | | | | | |
| ANT--2692 | 00511 | data | data | data | data | | not serviced | data |
| ANT--2792 | 00019 | data | data | data | data | | not serviced | data |
| ANT--2892 | 00123 | data | data | data | data | | not serviced | data |
| CLO--0050 | 00980 | data | data | data | data | | data | data |
| CLO--0051 | 00248 | data | data | data | not serviced | | not serviced | not serviced |
| CLO--0052 | 00947 | data | data | data | data | | data | data |
| KNY--0019 | 00483 | data | data | data | not serviced | | not serviced | not serviced |
| KNY--0033 | 00477 | data | data | data | not serviced | | not serviced | not serviced |
| KNY--0034 | 00998 | data | data | data | not serviced | | not serviced | not serviced |
| ***CNG Phase 2*** | | | | | | | | |
| ANT--0792 | 00977 | data | data | data | data | data | data | data |
| ANT--0892 | 00870 | data | data | data | data | data | data | data |
| ANT--0992 | 00987 | data | data | data | data | data | not serviced | data |
| ANT--1092 | 00253 | data | data | data | data | data | not serviced | data |
| ANT--1292 | 00118 | data | data | data | data | data | not serviced | data |
| ANT--1392 | 00181 | data | data | data | data | data | not serviced | data |
| ANT--1492 | 00185 | data | data | data | data | data | data | data |
| ANT--1592 | 00007 | data | data | data | data | data | data | data |
| ANT--1692 | 00489 | data | data | data | data | data | data | not serviced |
| ***CNG Phase 3*** | | | | | | | | |
| ANT--0296 | 01809 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ANT--0396 | 01717 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ANT--0696 | 01781 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CLO--0071 | 01931 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CLO--0073 | 00245 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CLO--0074 | 01986 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KNY--0031 | 02001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KNY--0035 | 02008 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KNY--0038 | 00263 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Figure 1.** A copy of the *File Status* sheet for the download on May 5, 1997. For descriptions of the files checked by *File Status,* please see Appendix 1. The Please note that CNG data collection was halted during this download and tankfill data is not collect for Diesel Phase 1 and Meth Phase 2.

**Figure 2.** Electronic mail accompanied each *File Status* report sent out by CE-CERT.

**Figure 3.** Response to CE-CERT's *File Status* and accompanying electronic mail.

**Appendix 5**
***DAS vs. Manual Checks***

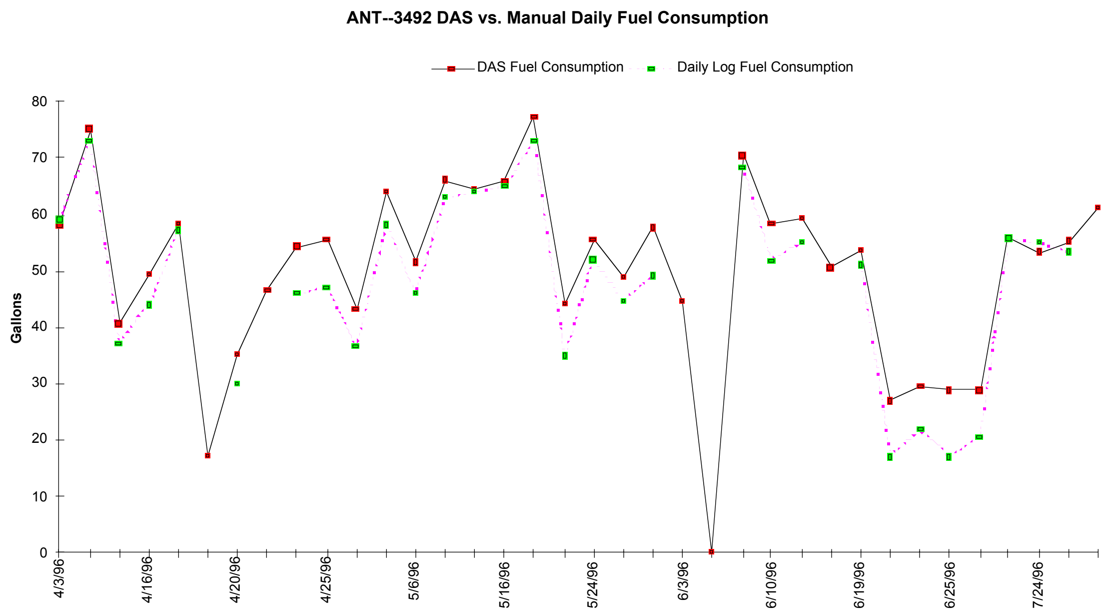



**Figure 1.** DAS fuel consumption compared to manual fuel consumption for ANT--3492, Diesel Phase 2. This bus illustrates a DAS unit that is consistently high when compared to the daily log.

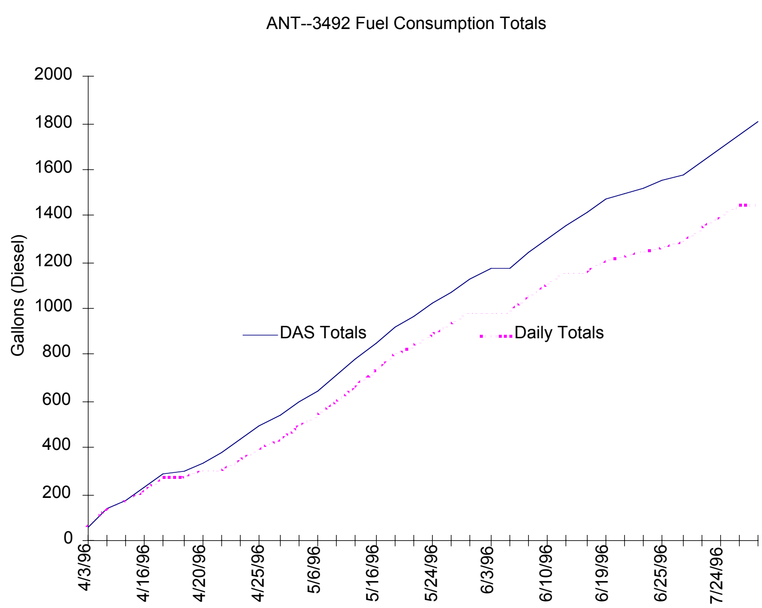



**Figure 2.** Cumulative DAS fuel consumption compared to Manual Fuel consumption for ANT—3492 over a two month period. After 1 year, following the trend, fuel consumption will have been misrepresented by 400 gallons, or 20%. The 20% error is also accounting for lost daily logged data because some fuel events were never recorded.

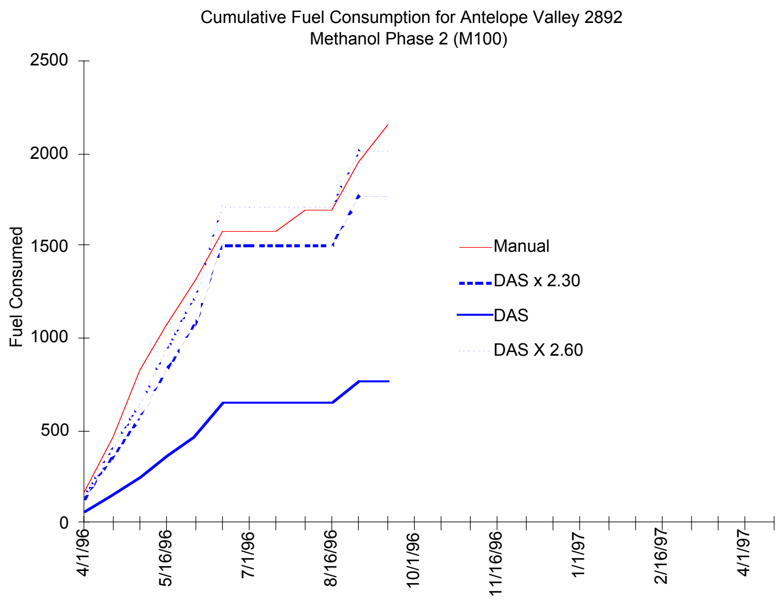



**Figure 3.** Manual fuel consumption compared with DAS fuel consumption for Methanol Phase 2 bus ANT-2892 before and after utilizing CE-CERT's conversion factor.

**Appendix 6**

***CE-CERT DAS Recalibration***

# Fuel Consumption Totals

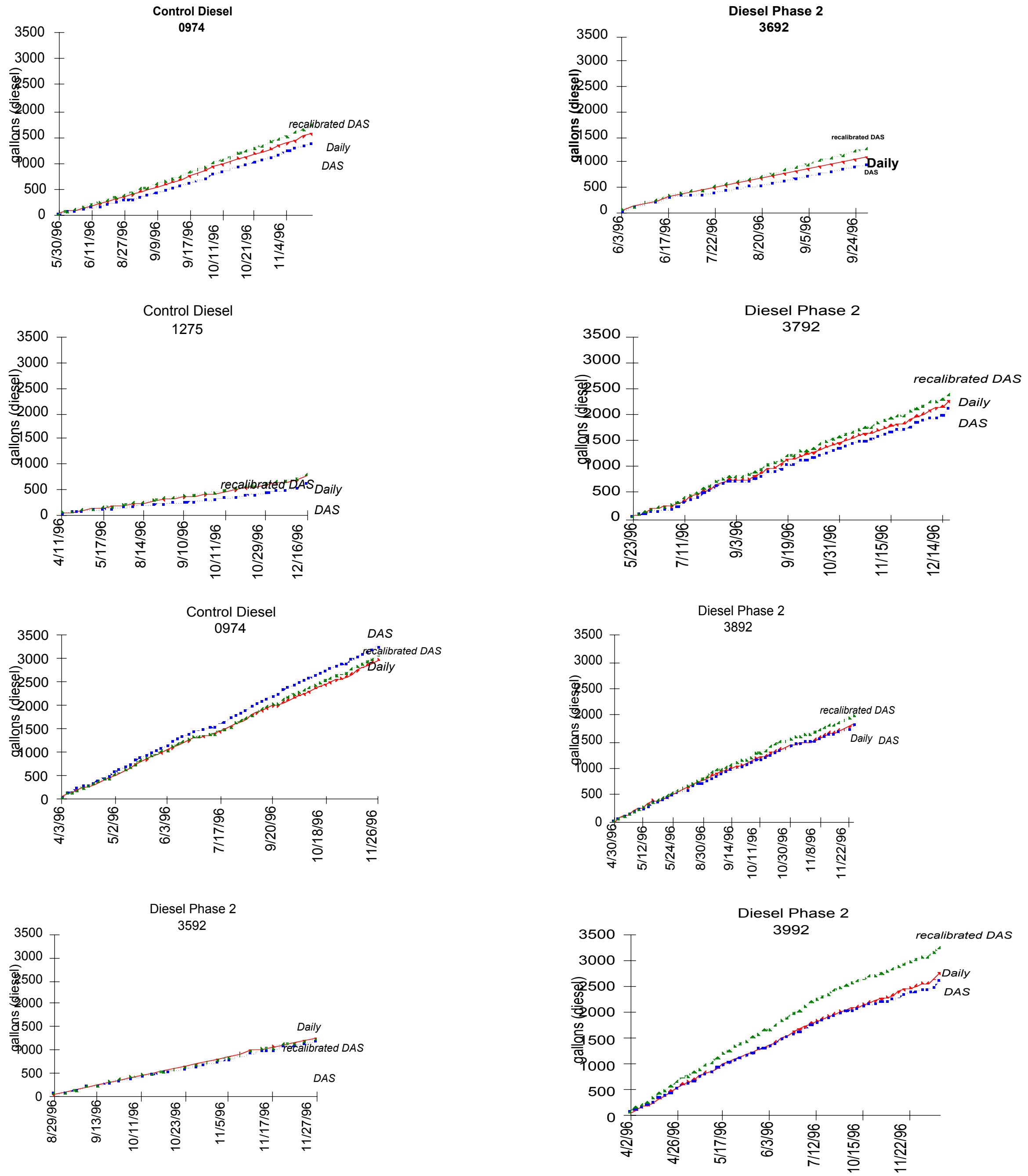



**Figure 1.** These 8 graphs are plots of DAS data, before and after CE-CERT re-calibration, compared to the Daily data.

| BUS # | %diff recalibrated DAS | %diff DAS | status |
|---|---|---|---|
| 0974 | 7.76% | 12.96% | *redo* |
| 1275 | 3.72% | 21.91% | *keep new coefficients* |
| 3492 | 2.80% | 8.54% | *keep new coefficients* |
| 3592 | 0.16% | 5.05% | *keep new coefficients* |
| 3692 | 15.54% | 10.97% | *redo* |
| 3792 | 6.68% | 6.23% | *redo* |
| 3892 | 8.67% | 1.93% | *use old coefficients* |
| 3992 | 18.78% | 5.53% | *redo* |

**Table1.** The percent difference between the DAS data and the Manual data based on the totals depicted in Figure 1.

| BUS # | ARGO # | *calibrated on:* |
|---|---|---|
| **Antelope Valley** | | |
| *Control Diesel* | | |
| 0974 | 00526 | 12/16/96 |
| 1074 | 00261 | 12/16/96 |
| 1275 | 00320 | 12/16/96 |
| 0022 | 00428 | 12/16/96 |
| *Diesel Phase 2* | | |
| 3492 | 00441 | 12/16/96 |
| 3592 | 00476 | 12/16/96 |
| 3692 | 00417 | 12/16/96 |
| 3792 | 00211 | 12/16/96 |
| 3892 | 00022 | 12/16/96 |
| 3992 | 00797 | 12/16/96 |
| **Kings Canyon** | | |
| *Control Diesel* | | |
| 0026 | 00425 | |
| 0030 | 00507 | |
| 0042 | 00009 | |
| *Diesel Phase 2* | | |
| 0056 | 00099 | |
| 0057 | 00358 | |
| 0058 | 00450 | |
| *Diesel Phase 3* | | |
| | | |
| | | |
| | | |
| | | |

| BUS # | ARGO # | *calibrated on:* |
|---|---|---|
| **Clovis** | | |
| *Diesel Phase 1* | | |
| 0021 | 01314 | |
| 0023 | 01015 | |
| 0024 | 00734 | |
| 0025 | 00763 | |
| 0026 | 00796 | |
| 0027 | 01216 | |
| 0029 | 00281 | |
| 0030 | 00871 | |
| 0031 | 00948 | |
| *Diesel Phase 3* | | |
| 0053 | | |
| 0054 | | |
| 0055 | | |
| 0067 | | |
| 0068 | | |

**Table 2.** The following is a list of the buses in the programs that were be recalibrated and the dates of their recalibration.

**Appendix 7**
***Constants and Equations***

## Constants

| Label | Value | Source |
|---|---|---|
| Natural Gas | | |
| Specific Gravity (SG) | 0.60 | Average specific gravity from PG&E Northern California |
| Molecular Weight (MW) | 17.4 g/mol | NG Table (Confirmed with PG&E and SoCal Gas |
| Lower Heating Value (LHV) | 20146 btu/lbm | US Mass transportation technical advisory paper. (California value) |
| Tank Volume (on school buses) | 0.82596 $m^3$<br>29.168502 $ft^3$ | Acurex (6 tanks), Bluebird Engineering (per tank = 0.137660, 6 * 0.137660 = 0.82596 |
| Therms per BTU | 100000.393 btu/Therm | Conversion Constant |
| Rou air | 0.07651 $lb/ft^3$ | Introduction to Fluid Dynamics, by Robert W. Fox @ 1 atm, sea level, 288K, 59F |
| Rou NG | 0.751 $kg/m^3$<br>0.045906 $lb/ft^3$ | NG Table (Confirmed with PG&E, SCGAS) |
| Pa | 0.00014504 psi | Conversion constant |
| Ru (N-m/gmol-k) | 8.3142 | Universal gas constant |
| Ru (lbf-ft/lbmol-R) | 1545 | Universal gas constant |
| Therms/scf North | 0.00944513 Therms/scf | Calculated from above data |
| Therms/scf South | 0.01059 Therms/scf | Southern California Gas Co. |

Equations

Mass Flow

mass flow (scfm) = 40.341*X-17.75
X (0.44-2.2V) = 1.07 X = 1.5 volts from the mass flow meter
mass flow (scfm) = 25.41
mass totalized 5 min (scf) = 127.07
mass flow (therm) = (scf)*(20146 but/lb)/(100000.3931 btu/therms)
mass flow (therms) = 25.60

PT Method

n = PV/(ZRuT)

Z (P,T, P>1000 C SG =0.6) = 1+[-0.15(P/1000)+exp(-2.87)*((P-1000)/1000)^1.87]*[1-0.14 ((T-75)/25)]
Acurex P > 1000 F and 25<T<75

Z (P,T, P<1000 C SG =0.6) = 1+[-0.15(P/1000)*[1-0.14 ((T-75)/25)]
Acurex P< 1000 F and 25<T<75

(scf) Units need attention = del(N)*MW/rouNG

mass flow (therm) = (scf)*(20146 but/lb)/(100000.3931 btu/therms)

CE-CERT Method

PV = nR(T + 273.15)Z

P = pascal (converted from psig + 14.7 = psia)
V = volume in m3
n = number of moles

R = universal gas constant
T = temperature in $^{o}C$
Z = compressibility factor

number of moles, n = (P+14.7)V/R(T+273.15)Z

Given the molecular weight, 17.4 g/mol and the density to be 0.751kg/m3, the number of moles can be converted into standard cubic feet:

(17.4 g/mol) * (0.001kg/g) / (0.751 kg/m3) = 0.023169108 m3 /mol
(0.023169 m3/mol) / (0.0283615 m3/ft3) = 0.816921103 ft3/mol

standard cubic feet, scf = n (0.816921103 ft3/mol)
= (P+14.7)V/R(T+ 273.15)Z (0.816921103 ft3/mol)

Using the volume V to equal 0.82596m3 and the universal gas constant R as 8.3142 N-m/mol K:

scf = ( 0.82596m3 * 0.816921103 ft3/mol )(P+14.7) / ( 8.3142 N-m/mol K )(T+273.15)Z
=0.080267505 (P+14.7)/(T+273.15)Z

therms, therm = scf * LHV / 100,000.4 btu

The total volume of 0.82596m3 is divided into six tanks. Thus the equation can be divided by six and the variable ALPHA can be introduced.

ALHPA= the number of tanks in use
therm = scf * LHV *ALPHA/ (6*100,000.4 btu)
therm = 1.33779E-07 *LHV*ALPHA* (P+14.7)/(T+273.15)Z